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Communications in Computer and Information Science 2345

Advanced Research in Technologies, Information, Innovation and Sustainability

4th International Conference, ARTIIS 2024
Santiago de Chile, Chile, October 21–23, 2024
Revised Selected Papers, Part I

Part 1

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ARTIIS

Communications in Computer and Information Science 2345

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Teresa Guarda · Filipe Portela · Gustavo Gatica
Editors

Advanced Research in Technologies, Information, Innovation and Sustainability

4th International Conference, ARTIIS 2024
Santiago de Chile, Chile, October 21–23, 2024
Revised Selected Papers, Part I

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Preface

The need for a greener and more digital world leads academia, governments, industry and citizens to look for emerging, sustainable and intelligent solutions and trends.

These new solutions and ideas must promote communication and ubiquitous computing between society agents, i.e., citizens, industry, organizations, networked machines and physical objects, and provide a promising vision of the future integrating the real world of knowledge agents and things with the virtual world of information. The emerging approaches in study or development may address several dimensions with a technological focus like Information, Innovation and Sustainability and topics such as Computing Solutions, Data Intelligence, Ethics, Security, Privacy and Sustainability.

These topics are closely related to the field of Information Systems (IS) because all of them involve the use and management of technology and data to achieve specific purposes or goals. Computing Solutions are a crucial aspect of information systems as they provide the technical infrastructure and tools for organizations to manage and process data. Data Intelligence is also a key area of information systems as it involves the collection, analysis and interpretation of data to support decision-making and problem-solving. Sustainability is becoming an increasingly important aspect of information systems as organizations are recognizing the impact of technology on the environment and are looking for ways to reduce their carbon footprint. Ethics, Security and Privacy are also essential aspects of information systems as they involve the responsible and secure use of technology and data to protect individuals and organizations from potential harm.

The change observed in society modifies the landscape of human activity, particularly regarding knowledge acquisition and production, offering new possibilities and challenges that need to be explored, assessed and disseminated.

ARTIIS is an international forum for researchers and practitioners to present and discuss the most recent innovations, trends, results, experiences and concerns from several perspectives of Technologies, Information, Innovation, and Sustainability.

The conference was held in a hybrid format, with some participants present in person, in Santiago de Chile, Chile, hosted by the Universidad Andrés Bello. We enabled virtual participation for those who were unable to attend the event, due to logistical, political, economic or other issues, by adopting the infrastructure of the Zoom platform.

These three volumes (CCIS volumes 2345–2346–2347) consist of the peer-reviewed papers from the 2024 International Conference on Advanced Research in Technologies, Information, Innovation and Sustainability (ARTIIS 2024), which took place during October 21–23, 2024. In addition, the peer-reviewed papers of the 13 Workshops, the Workshops proceedings, are published in a separate set consisting of two volumes (CCIS 2348–2349).

The first volume of the book (CCIS volume 2345) contains all the papers on the topic Computing Solutions: that addresses the development of applications and platforms involving computing for use in some area of knowledge or society. It includes topics such as networks, pervasive computing, gamification and software engineering.

The second volume (CCIS volume 2346) contains all the papers on the topic Data Intelligence: it focuses on data (e.g., text, images) acquisition and processing using smart techniques or tools. It includes topics such as Computing Intelligence, Artificial Intelligence, Data Science and Computer Vision.

The third volume (CCIS volume 2347) contains all the papers on the topics Sustainability, Ethics, Security and Privacy. Sustainability explores a new type of computing, more green, connected, efficient and sustainable. Topics such as Immersive Tech, Smart Cities and Sustainable Infrastructures are part of this topic. Ethics, Security and Privacy involves a more strict and secure area of Information Systems where the end-user is the main concern. Vulnerabilities, Data Privacy and cybersecurity are the main subjects of this topic.

The fourth edition of ARTIIS, realized in 2024, received 408 contributions from 44 countries worldwide. The acceptance rate was 38%, 138 regular papers and 18 short papers. We accepted 83 full papers, and 8 short papers from 238 submissions to the Main Conference. For the 14 workshops we accepted 55 full papers and 10 short papers from 170 submissions.

ARTIIS 2024 had the support of Universidad Andrés Bello, Chile; Universidad Estatal Península de Santa Elena, Ecuador; and the Algoritmi Research Center of Minho University, Portugal.

The Program Committee was composed of a multidisciplinary group of more than 453 experts from 57 countries, with the responsibility for evaluating, in a double-blind review process, the papers received for each of the main themes proposed for the conference and workshops.

The success of the ARTIIS conference series, and especially ARTIIS 2024, reinforces our commitment to continuing this valuable work. We extend our sincere gratitude to everyone who contributed to this achievement: Authors, Presenters, Participants, Keynote Speakers, Workshop Chairs, Session Chairs, Organizing Committee members, Student volunteers, General Chairs, Program Committee members, Steering Committee members, Communication Chair and Reviewers.

We also wish to thank our publisher, Springer, for their agreement to publish the proceedings, and for their kind and professional assistance.

We cordially invite you to visit the ARTIIS website https://artiis.org.

November 2024

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Applications of Computational Mathematics to Simulation and Data Analysis (ACMaSDA 2024)
Business, Technology and Digital Transformation (BTDT 2024)
Challenges and the Impact of Communication and Information Technologies on Education (CICITE 2024)
Emergent Technologies and Artificial Intelligence (ET-AI 2024)
Intelligent Systems for Health and Medical Care (ISHMC 2024)
Workshop on Gamification Application and Technologies (GAT 2024)
Smart Tourism and Information Systems (SMARTTIS 2024)
International Symposium on Technological Innovations for Industry and Society (ISTIIS 2024)
International Workshop on Electronic and Telecommunications (IWET 2024)
Boosting Tourism using New Technologies (#RTNT2024)
Cybersecurity in Information and Communication Technologies (CICT 2024)
Bridging Knowledge in a Fragmented World (glossaLAB 2024)
Workshop on IoT Networks and Wireless for Sustainability (WIN-WIN-4S 2024)
Innovation in Educational Technology (JIUTE 2024)

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Plenary Lectures

Long-Term Strategic Development for STEM Higher Education Instructors: Trends, Challenges, and Insights from the FIT4FUTURE Project

Nuno Pombo

University of Beira Interior, Portugal

Abstract. The FIT4FUTURE project, co-funded by the EU Erasmus+ program, focuses on equipping STEM higher education instructors with the skills and methodologies to incorporate Long-Term Future Scenarios (LTFS) into their teaching practices. By bridging future research with traditional strategic management, FIT4FUTURE addresses gaps in academic training, fostering a forward-looking mindset and enhancing the employability of students in high-tech industries. Through a structured methodology, the project includes curriculum design, content development, an online learning platform, and program implementation. Key features of the platform include tutorials, case studies, and industry insights on LTFS methods like trend extrapolation, simulation models, and creative exercises such as flash fiction and science fiction film analysis. These tools aim to empower educators to adopt innovative approaches and inspire student engagement by exploring future possibilities and challenges.

Survey and interview results highlight a significant interest among educators in learning about LTFS methods, with over 85% expressing enthusiasm for acquiring this knowledge. However, a majority lack familiarity with such techniques. Educators who have implemented LTFS methods report increased student enthusiasm, as these scenarios help learners envision future decision-making and societal impacts. FIT4FUTURE thus provides a comprehensive framework for integrating long-term strategic thinking into STEM education, ensuring a richer, more dynamic learning experience that prepares students and educators to navigate the evolving demands of the twenty-first century.

The Challenges of Evolving Digital Ethics Frontiers

Simon Rogerson

De Montfort University, UK

Abstract. There now exists global deep-seated dependency on digital technology. This dependency presents huge challenges. The key element in the digital age is not digital technology; it is people – be they planners, funders, researchers, developers, implementers, users or those indirectly affected by digital technology usage. We all have moral obligations and responsibilities to ensure the digital age is inclusive and empowering rather than exclusive and constraining.

The digital technology frontiers are littered with ethical hotspots where activities and decision making are likely to include a relatively high ethical dimension and consequently are likely to have the greatest impact on society, its culture and its people. Typical examples are discussed including: the contrasting impact of COVID 19 on digital natives and digital outcasts; software developed by Volkswagen to cheat on emissions tests; the flawed Horizon system developed by Fujitsu for the UK Post Office; and Crowdstrike's faulty software update leading to the greatest IT outage ever. AI and Smart Living are explored in detail to illustrate the increasing challenge of realising ethical digital technology and how to rise to that challenge.

Naval Logistics in Antarctica: A Challenge in Extreme Conditions

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Abstract. Naval logistics in Antarctica face significant challenges due to extreme cold conditions, ice, geographic isolation, and a fragile ecosystem requiring rigorous protection. This work presents an innovative approach that integrates advanced algorithms and mathematical models to address logistical challenges on the southernmost continent. Safe route planning through ice-covered waters relies on combinatorial optimization models and heuristic algorithms based on satellite data and weather forecasts. These tools enable the dynamic identification of optimal trajectories, minimizing the risk of collisions with icebergs and maximizing transit efficiency. In addition, stochastic models are used to anticipate variability in weather conditions and operating times, improving responsiveness to uncertain scenarios.

Resource management on board and at Antarctic bases uses discrete simulation models to optimize fuel, food, and equipment storage and consumption. In parallel, reverse logistics algorithms ensure the efficient collection of waste and its transfer to processing areas, reducing the environmental impact. International cooperation in Antarctica relies on collaborative resource allocation models and shared logistics networks, allowing for better distribution of loads and capacities. This approach based on data science and applied mathematics strengthens operational resilience, promotes sustainability and optimizes logistics operations in one of the most challenging environments on the planet.

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Computing Solutions

COVID-19 Pandemic Management: A Cloud-Based Electronic Health Record System

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Abstract. This study introduces a Cloud-based Electronic Health Record (EHR) system tailored to effectively manage the coronavirus disease 2019 (COVID-19) pandemic. Amidst global healthcare challenges, robust patient data management is paramount, necessitating innovative solutions. Leveraging cloud computing technology, our proposed system offers scalability and accessibility advantages over traditional EHR systems. Key features include graphical data representation for analysis, facilitating early identification and monitoring of COVID-19 cases. Security measures ensure protection of sensitive patient data and compliance with privacy laws. Survey results from healthcare professionals validate the system′s efficacy and relevance. In conclusion, our study presents a comprehensive solution to pandemic management, addressing critical needs for data security, scalability, and accessibility in healthcare institutions worldwide.

Keywords: COVID-19 Pandemic Management · Cloud-based Electronic Health Records · Healthcare Professionals and Patients

1 Introduction

This research investigates the utilization of cloud-based Electronic Health Record (EHR) systems for preserving and sharing health records while enhancing medical services, with a specific focus on their application in the efficient management of the COVID-19 pandemic. Cloud technology offers advantages such as interoperability, scalability, and cost-effectiveness, making it a suitable solution for securely maintaining patient health records [1-3]. The research aims to systematically organize medical records to facilitate improved management of COVID-19 patients.

The motivation for this research stems from the global digitalization of healthcare services, marked by the transition from paper-based medical records to electronic formats [1, 4]. Additionally, the study explores the role of coding techniques and cloud-based systems in safeguarding patient data privacy [2, 3, 5].

EHR systems serve as electronic repositories of patient history, aiding physicians in tracking health information and facilitating various aspects of healthcare delivery,

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including diagnosis and therapy [6, 7]. With the emergence of the COVID-19 pandemic, the imperative for efficient patient data management has become increasingly evident. This highlights the need for further research into cloud-based EHR systems that automate processes while ensuring robust data security [8].

The primary objective of this study is to develop and evaluate a cloud-based EHR system specifically designed to address the challenges posed by the COVID-19 pandemic. Our research contributes to the field by proposing a novel system architecture and validating its effectiveness through expert feedback. While this study focuses on implementation within the Macedonian healthcare system, the proposed architecture is designed with potential scalability for multi-country adoption in future research.

Furthermore, the system′s flexible design allows for the integration of new COVID-19 treatment findings as they emerge, enhancing its long-term value and adaptability to evolving pandemic management strategies.

The remainder of this paper is structured as follows: Sect. 2 discusses the critical role of EHRs in managing health information during the COVID-19 pandemic. Section 3 provides a detailed representation of the proposed EHR system. Section 4 describes the methodology and results of a survey conducted among Macedonian medical experts. Finally, Sect. 5 concludes the paper and suggests directions for future research, including potential multi-country studies and integration of emerging COVID-19 treatments.

2 Leveraging EHR Systems for Effective COVID-19 Management

2.1 Transition to Digital Health Records

In many developed countries, Health Information Systems (HIS) have increasingly relied on Electronic Health Records (EHRs). This research proposes a cloud-based EHR system to facilitate the transition from traditional paper-based records to more efficient digital systems [9]. The primary advantage of such systems lies in their ability to enable seamless data sharing among healthcare providers, thereby enhancing collaboration and improving overall patient care [10].

2.2 Role of EHRs in Pandemic Response

The COVID-19 pandemic has emphatically underscored the critical importance of maintaining reliable and accessible patient records [11]. Large-scale data sharing, made possible by EHR systems, has played an instrumental role in understanding the virus′s behavior and formulating effective responses to the pandemic [12, 13]. Furthermore, several studies have highlighted the potential of EHR data in COVID-19 research, offering valuable insights into risk factors and patient outcomes [15, 16].

One of the key benefits of EHR systems during the pandemic has been their capacity for real-time patient monitoring, which aids in early detection and timely treatment of COVID-19 cases [17]. A notable example of EHR adaptability comes from UC San Diego Health, which developed COVID-19-specific tools using its existing EHR infrastructure [18]. This case demonstrates how EHR systems can be rapidly tailored to address specific healthcare crises, showcasing their flexibility and potential in managing public health emergencies.

Moreover, EHR systems can be designed to rapidly incorporate and disseminate new findings on COVID-19 treatments, ensuring that healthcare providers have access to the most up-to-date information for patient care.

2.3 Challenges and Future Directions

Despite the evident benefits of EHR systems, several challenges persist in their implementation and use. These include issues related to data governance and interoperability among different healthcare systems [14]. While EHR technologies have undoubtedly demonstrated their value during the pandemic, there is a clear need for further enhancements to improve their effectiveness in pandemic control strategies [19].

Looking ahead, future research should focus on refining these systems to better support public health crisis management. Our study aims to propose a more organized approach that leverages the findings from recent experiences to enhance pandemic management procedures. By addressing current limitations and building upon existing successes, we can develop more robust and effective EHR systems capable of meeting future healthcare challenges.

While our current study focuses on implementation within a single country, future research should explore the adaptability of cloud-based EHR systems across multiple countries. This would provide valuable insights into the scalability and effectiveness of such systems in diverse healthcare environments.

3 System Architecture and Comprehensive Functionality

3.1 System Architecture

The proposed Electronic Health Record (EHR) system employs a three-layer architecture consisting of a data acquisition layer, a data store layer, and a data exchange layer. Figure 1 illustrates this architecture.

Data Acquisition Layer
This layer is represented by the user interface of the system, primarily the web application. It gathers medical data from a variety of sources, encompassing patients, healthcare providers, and external sources accessible to system users. Medical professionals, as the primary users, employ the web application to input medical data and manage patients' records. The interface is designed with intuitive navigation and efficient data entry in mind, features that are crucial for rapid response during a pandemic. This design enables healthcare providers to quickly and accurately record and access patient information, facilitating timely and informed decision-making in the fast-paced environment of pandemic management.

Data Storage Layer
The storage layer is responsible for securely storing medical records for future access. It incorporates several key features to ensure data integrity and accessibility. This layer

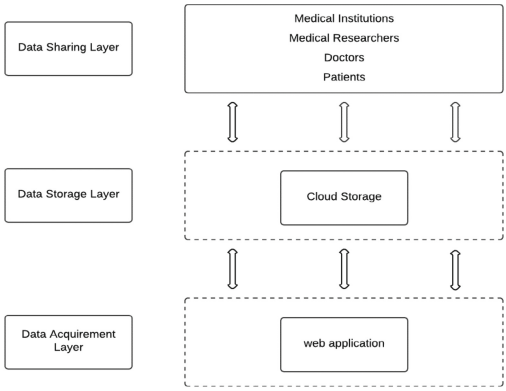

Fig. 1. System Architecture

performs data cleaning, transformation, and structuring to facilitate authorized personnel access. It implements cloud storage, ensures secure data sharing, and stores registered patients' medical records along with their associated access rights. We utilize Firebase as our primary database service, chosen for its scalability and robust security features. Firebase′s NoSQL structure allows for flexible data modeling, that is essential for adapting to the evolving data requirements of pandemic management. This flexibility enables the system to accommodate new types of data or changes in data structure as our understanding of COVID-19 and its management evolves.

Data Sharing Layer

The data sharing layer enables authorized users, such as hospitals and researchers, to request and access electronic medical records. This functionality facilitates comprehensive analysis of COVID-19 vaccination statistics, enhances healthcare records management, and supports real-time data sharing for effective pandemic response coordination. To safeguard patient privacy and ensure data security, we implement rigorous protection measures, including role-based access control and end-to-end encryption for all data transfers. These security protocols ensure that sensitive medical information is only accessible to authorized personnel, maintaining patient confidentiality while allowing for crucial data analysis and collaborative pandemic management efforts.

3.2 Project Tools and Setup

Frontend Development

We utilize Angular for creating client-side web and mobile applications, chosen for its component-based architecture that facilitates code reuse, strong typing with TypeScript that reduces runtime errors, and comprehensive testing tools. The development process leverages several key technologies and tools: Angular CLI for project initialization and task management, the Sakai PrimeNG Angular admin template for pre-designed UI components, and Node.js with npm for dependency management and build processes. This combination of frameworks and tools enables efficient, robust, and scalable frontend development, crucial for the complex requirements of our EHR system.

Backend Development
For our backend solution, we leverage Firebase, which offers a comprehensive suite of features including real-time database capabilities, built-in authentication services, and Cloud Functions for serverless computing. To enhance data security and privacy compliance, we implement custom security rules in Firebase, ensuring that only authorized individuals can access and modify medical records. This robust backend infrastructure, combined with Angular for frontend development, provides a scalable and secure foundation for our EHR system. The resulting architecture facilitates rapid development and deployment of new features, a crucial capability for adapting to the evolving needs of pandemic management. This integrated approach allows us to maintain high performance and data integrity while remaining agile in response to changing healthcare requirements and emerging COVID-19 challenges.

3.3 Key System Components

Dashboard
The dashboard (Fig. 2) provides a customized overview for each user, displaying:

- Total examinations in the facility
- COVID-19 examinations by the logged-in doctor
- Total recovered and deceased patients
- Daily examination data table

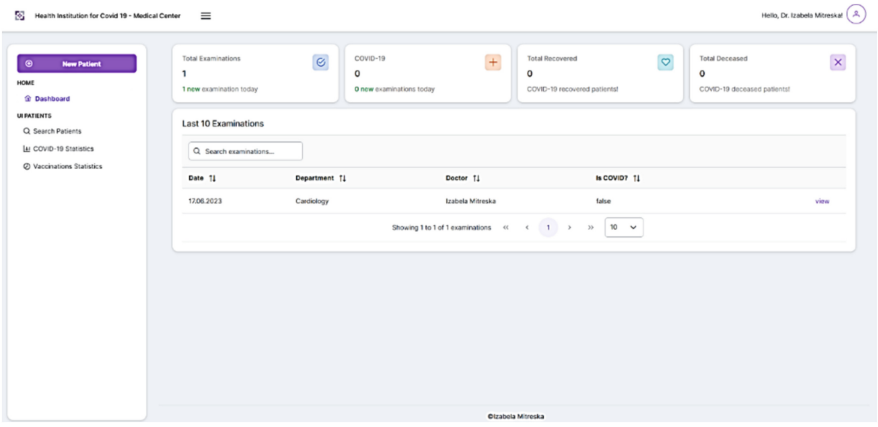

Fig. 2. Representation of the Dashboard Page in the proposed EHR system

Patient Profile
The patient profile page (Fig. 3) allows users to:

- Search for registered patients
- Register new patients

- View detailed patient information
- Create new general and COVID-19 examinations

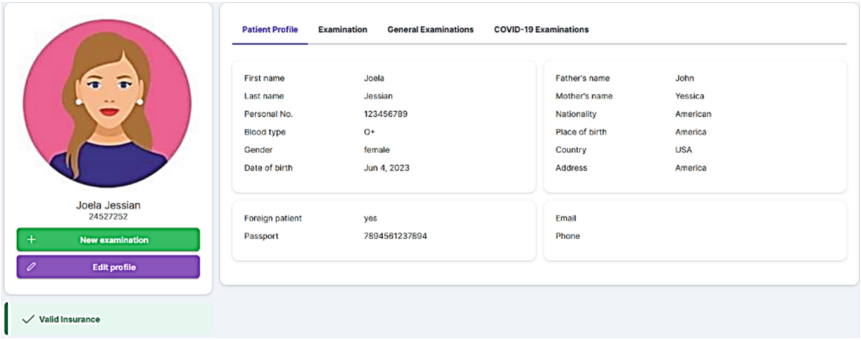

Fig. 3. Representation of the Patient Profile Page of the proposed EHR system

Examination Models
The system supports two types of examinations:

1. *General Examination* (Fig. 4):
   - Includes fields for examination date, department, diagnosis, therapies, and body measurements
   - Displays created examinations in a data table for easy access
2. *COVID-19 Examination* (Fig. 5 and 6):
   - Incorporates all general examination fields
   - Adds sections for COVID-19 vaccination and patient status indicators
   - Provides a separate data table for COVID-19 examinations

Diagnosis and Therapies Management
The system includes comprehensive forms for managing diagnoses (Fig. 7) and therapies (Fig. 8). These forms ensure data integrity by:

- Preventing duplicate entries
- Requiring valid data input
- Allowing for flexible dosage and treatment frequency recording

Measurements
The system captures various health measurements, including:

- Body measurements (weight, height, temperature)
- Blood test results

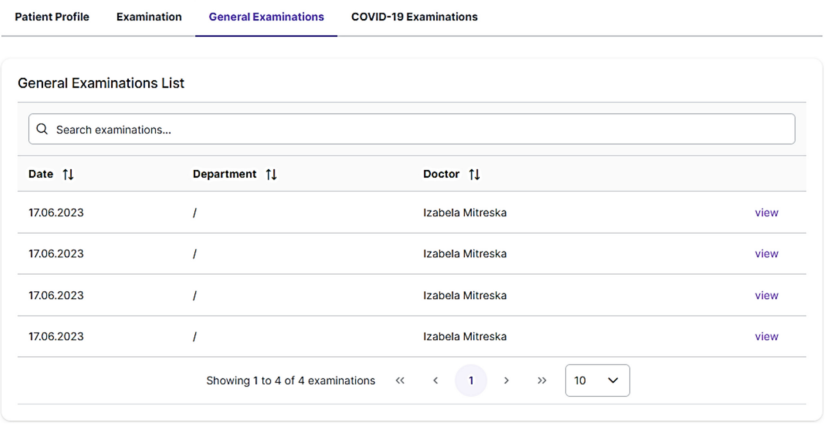

Fig. 4. Table representation of the General Examination in the proposed EHR system

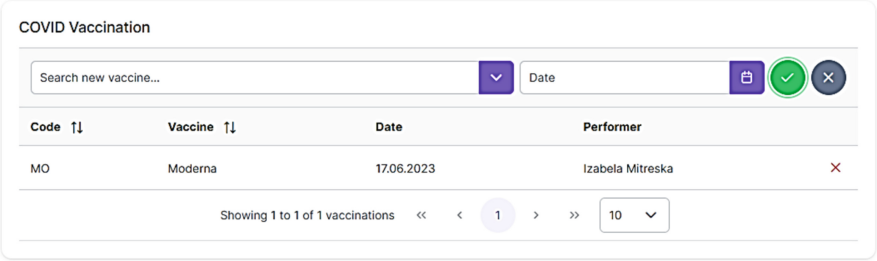

Fig. 5. Representation of the COVID Vaccination form of the proposed EHR system

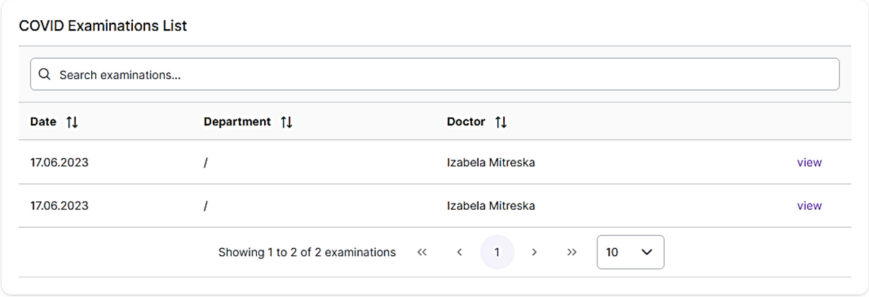

Fig. 6. Representation of COVID Examination List in the proposed EHR system

Figure 9 shows the body measurements form, which includes validation to ensure accurate data entry.

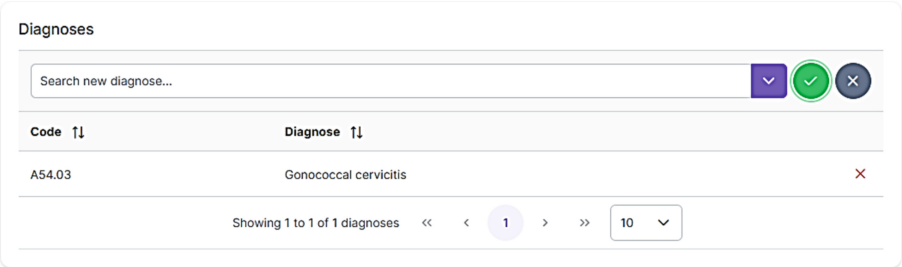

Fig. 7. Diagnosis form in the proposed EHR system

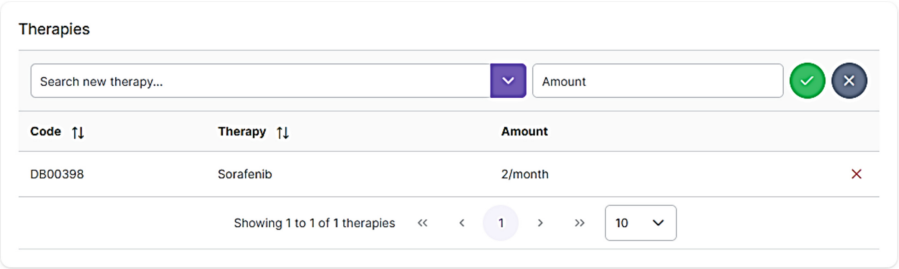

Fig. 8. Therapies form in the proposed EHR system

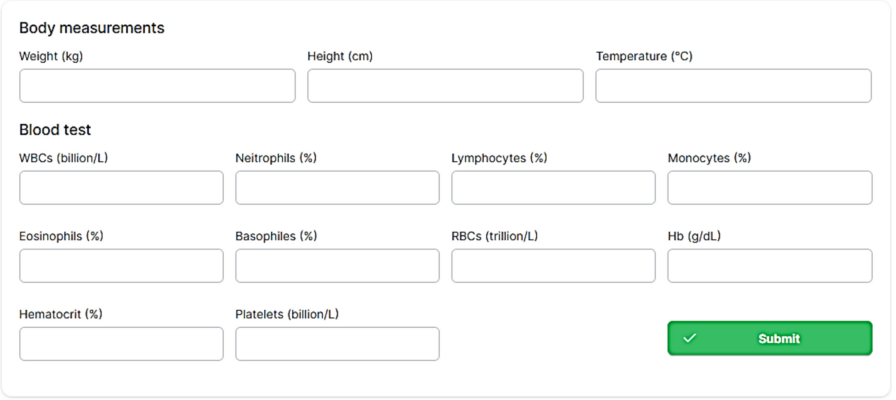

Fig. 9. Body measurements form of the proposed EHR system

COVID-19 Statistics

The application provides detailed COVID-19 statistics, including:

- Comparison of COVID-19 vs. general examinations (Fig. 10)
- Patient status (deceased, recovered, active cases)
- Various COVID-19 diagnosis types

- Integration of new COVID-19 treatment findings, allowing for rapid dissemination of up-to-date treatment protocols to healthcare providers

These statistics are automatically generated and updated as new data is entered into the system.

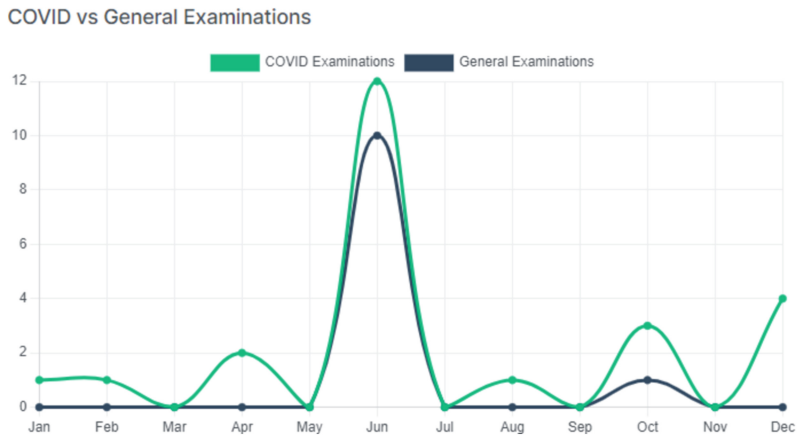

Fig. 10. Representation of Covid vs General Examinations included in the proposed EHR system

Vaccination Statistics
The system tracks and displays vaccination data, including:

- Deployment schedule
- Distribution over different months
- Coverage levels
- Impact on COVID-19 transmission and mortality rates

This feature allows for real-time monitoring of vaccination efforts and their effectiveness in managing the pandemic.

3.4 Scalability and Future Improvements

Our system's modular architecture facilitates easy scalability and future enhancements. Potential improvements encompass integration with wearable devices for real-time patient monitoring, implementation of machine learning algorithms for predictive analytics, and enhanced interoperability with other healthcare systems through standardized APIs. The system's design also considers potential multi-country deployment, enabling future studies to explore its effectiveness across diverse healthcare systems and regulatory environments.

4 Survey-Based Analysis

4.1 Introduction to the Survey

This section presents the results of a perception survey conducted on the "Health Institution for COVID-19" application. The survey aimed to understand factors influencing integrated healthcare services and assess the satisfaction and importance of the proposed system among health professionals in North Macedonia.

4.2 Survey Methodology

Survey Design and Implementation

The survey was conducted in April 2023 over one month, targeting health professionals including students enrolled in medical sciences, general and family practitioners, and specialist doctors. Participation was restricted to health workers in facilities using the National System of the Republic of North Macedonia, and consent was required for participation.

Survey Structure

The questionnaire consisted of 36 questions covering various aspects, including personal data, experience in remote settings, exhaustion levels, patient interactions, and system satisfaction.

Statistical Analysis

The comparative analysis was performed using the Mann-Whitney U test, a non-parametric statistical test for comparing two independent groups. This test assesses whether there is a statistically significant difference between the distributions of the two groups based on their ranks.

4.3 Profile of Health Professionals

A total of 34 health professionals responded to the survey. Key demographics include:

- 94.1% worked in urban areas
- Age range: 20–65 years (average: 42.5 years)
- Professional breakdown:
  - General medicine doctors: 73.5%
  - Family medicine doctors: 2.9%
  - Specialist doctors: 20.6%

4.4 E-health Services in North Macedonia

This section explores the landscape of E-health services in North Macedonia by analyzing survey questions designed to assess various dimensions of healthcare provision.

Table 1 presents detailed responses from general medicine doctors and specialist doctors to the survey questions outlined in this part, offering a comprehensive overview of their perspectives and experiences with E-health services in North Macedonia.

Table 1. E-health services in North Macedonia

E-health services in North Macedonia	Profession		Total
	General medicine doctor	Specialist doctor	
How often do you have access to your patients' latest test or examination results when you need it?			
Never	12.0%	0.0%	9.3%
Rarely	4.0%	0.0%	3.1%
Sometimes	24.0%	0.0%	18.8%
Often	32.0%	57.1%	37.5%
Always	28.0%	42.9%	31.3%
Do you get a report from a specialist or hospital if your patient visited them?			
Never	0.0%	0.0%	0.0%
Rarely	12.0%	28.6%	15.6%
Sometimes	44.0%	14.2%	37.5%
Often	28.0%	28.6%	28.1%
Always	16.0%	28.6%	18.8%
Since the beginning of the pandemic, have you received patients with symptoms of COVID-19?			
Yes	100.0%	100.0%	100.0%
No	0.0%	0.0%	0.0%
Does the national system (Мој термин) provide you with data on persons admitted by you with symptoms of COVID-19?			
Yes	100.0%	100.0%	100.0%
No	0.0%	0.0%	0.0%
Do you think it is important that the national system (Мој термин) provides you with continuous data on the condition of persons who have been confirmed to be infected with COVID-19and were admitted by you with symptoms of COVID-19?			
Very important	76.0%	57.1%	71.9%
Important	20.0%	28.6%	21.9%
Fairly important	4.0%	0.0%	3.1%
Slightly Important	0.0%	14.3%	3.1%
Not Important	0.0%	0.0%	0.0%
Does the application "Health Institution for COVID-19" give you the opportunity to record data on the continuous condition of people with symptoms of Covid 19?			
Yes	96.0%	100.0%	96.9%
No	4.0%	0.0%	3.1%
Is the data on the continuous condition of persons with symptoms of COVID-19 comprehensibly presented in the application?			
Yes	100.0%	85.7%	96.9%
No	0.0%	14.3%	3.1%
How helpful is it to have statistics like the "Healthcare Institution for COVID-19" application for your patients with symptoms of COVID-19?			
Very important	72.0%	71.4%	71.9%
Important	28.0%	28.6%	28.1%
Fairly important	0.0%	0.0%	0.0%
Slightly Important	0.0%	0.0%	0.0%
Not Important	0.0%	0.0%	0.0%
Would you like this application to be part of the National System (Мој термин) to be able to monitor the condition of your patients with symptoms of COVID-19?			
Yes	100.0%	100.0%	100.0%
No	0.0%	0.0%	0.0%
What do you think is important to add to the application "Health Institution for COVID-19"?			
It is satisfactory as it is	100.0%	100.0%	100.0%
Other	0.0%	0.0%	0.0%

4.5 Detailed Analysis of Survey Responses

1. ***Access to Patient Information:*** The analysis reveals significant disparities between general medicine doctors and specialists regarding access to patients' latest test or examination results. While 12.0% of general medicine doctors reported never having access, no specialists indicated the same. Specialists showed higher rates of often having access (57.1%) compared to general medicine doctors (32.0%). Similarly, 42.9% of specialists always had access, slightly higher than 28.0% of general medicine doctors. The Mann-Whitney U test confirms this difference ($z = –1.577$, $p = 0.115 < 0.15$ - 2-tailed significance). These findings suggest that specialists generally have more reliable access to patient results, possibly due to specialized workflows and resources. Conversely, general medicine doctors may face challenges in accessing patient information, indicating the need for system improvements.
2. ***Receiving Reports from Specialists or Hospitals:*** Both groups reported never receiving reports at 0.0%, indicating established systems for timely report delivery. However, 12.0% of general medicine doctors and 28.6% of specialists reported rarely receiving reports, suggesting differences in frequency. General medicine doctors more often reported sometimes receiving reports (44.0%) compared to specialists (14.3%), indicating varying communication levels. Both groups reported similar frequencies for often receiving reports (28.0% and 28.6%, respectively). While both reported high percentages for always receiving reports (16.0% and 28.6%), specialists had a slightly higher frequency. Mann-Whitney U test results ($z = –0.238$, $p = 0.812 > 0.05$ - 2-tailed significance) suggest no significant statistical difference between the two groups.
3. ***Importance of Continuous COVID-19 Data:*** Both groups highly prioritize the national system "Moj термин" providing continuous data on COVID-19 patients, with 76.0% of general medicine doctors and 57.1% of specialists considering it "very important." Overall, 71.9% of respondents agree on its crucial role in patient care. Additionally, 20.0% of general medicine doctors and 28.6% of specialists find it "important," totaling 21.9% of all respondents. A minority perceive it as "fairly important" (4.0% of general medicine doctors) or "slightly important" (14.3% of specialists), but none regard it as unimportant. Mann-Whitney U test results ($z = –1.072$, $p = 0.284 > 0.05$) affirm no significant statistical difference between the two groups.
4. ***Recording COVID-19 Patient Data:*** A substantial majority of both general medicine doctors (96.0%) and specialists (100.0%) confirm that the "Health Institution for Covid 19" application allows them to record continuous condition data of COVID-19 patients. Overall, 96.9% of all respondents acknowledge this capability. However, a small percentage of general medicine doctors (4.0%) reported not having this opportunity. Mann-Whitney U test results ($z = –0.529$, $p = 0.597 > 0.05$) confirm no significant statistical difference between the two groups, suggesting uniform access to this functionality.
5. ***Data Comprehensibility:*** All general medicine doctors (100.0%) and a majority of specialists (85.7%) find the data on the continuous condition of COVID-19 patients comprehensibly presented in the application, totaling 96.9% of all respondents. None of the general medicine doctors reported data incomprehensibility, while 14.3% of specialists did. The Mann-Whitney U test ($z = –1.890$, $p = 0.059 < 0.06$) indicates

a significant statistical difference between general medicine doctors and specialists, with 96% statistical significance, regarding the data′s comprehensibility.

6. ***Importance of Statistics:*** A significant majority of both groups (72.0% of general medicine doctors and 71.4% of specialists) consider having statistics in the application very important for patients with COVID-19 symptoms, totaling 71.9% of all respondents. Additionally, 28.0% of general medicine doctors and 28.6% of specialists find it important. None of the respondents indicated lower levels of importance. The Mann-Whitney U test ($z = –0.029$, $p = 0.977 > 0.05$) indicates no significant statistical difference between general medicine doctors and specialists regarding the helpfulness of these statistics.

These findings underscore the application′s importance in enabling healthcare providers to effectively monitor and document COVID-19 patients' ongoing conditions, emphasizing the critical role of real-time data tracking in informed decision-making and comprehensive patient care.

4.6 Limitations and Future Work

While this study provides valuable insights into the perception and use of E-health services in North Macedonia, it has some limitations:

- *Single-country focus*: The study was conducted only in North Macedonia. Future research could expand to multiple countries for a comparative analysis of E-health adoption and perception.
- *Sample size*: With 34 respondents, a larger sample size in future studies could provide more robust findings.
- *Time frame*: The survey was conducted over one month. A longitudinal study could offer insights into changing perceptions over time, especially as the COVID-19 situation evolves.

Future work could address these limitations and also explore:

- Integration of new COVID-19 treatment findings into the application
- Comparative analysis of E-health adoption across different healthcare systems
- Impact of E-health tools on patient outcomes and healthcare efficiency

5 Conclusion

The development of a cloud-based Electronic Health Record (EHR) system represents a significant advancement in addressing the challenges posed by the COVID-19 pandemic. By leveraging cloud computing technologies, smart data analytics, and robust security measures, the system offers numerous benefits for healthcare professionals, researchers, and policymakers in effectively managing the crisis.

Integration of an EHR system on the cloud promotes collaboration among healthcare professionals, streamlines workflows, and enables real-time data sharing and analysis. This facilitates prompt identification, monitoring, and action in COVID-19 cases, ultimately improving patient outcomes and optimizing resource utilization.

Security and privacy are paramount in healthcare systems, especially when handling sensitive patient data. The cloud-based EHR system ensures patient data security and compliance with privacy laws, fostering trust between patients and providers. However, opportunities for further development exist. Enhancements such as integrating telemedicine, improving interoperability, and enhancing long-term health monitoring capabilities can increase the system′s efficiency and effectiveness.

Based on our survey findings regarding the "Health Institution for COVID-19" application in North Macedonia:

- Most general medicine doctors and specialist doctors have access to recording data on the continuous condition of individuals with COVID-19 symptoms through the application, highlighting its widespread utilization among healthcare providers.
- The data presentation in the application is mostly found to be comprehensible by both general medicine doctors and specialist doctors, though there is room for improvement in certain areas.
- Statistical data availability within the application is deemed highly important by the majority of doctors, emphasizing the need for comprehensive and up-to-date insights for effective patient management.
- There is a unanimous desire among respondents for the integration of the application into the national system (Мој термин), indicating the importance of a unified system for monitoring and managing patients with COVID-19 symptoms.
- Overall, respondents find the application satisfactory as it is, suggesting no specific improvements or additions were suggested during the survey.

While this study focused on North Macedonia, future research could extend to multiple countries, providing valuable comparative insights into EHR adoption and effectiveness across different healthcare systems. Additionally, as new findings about COVID-19 treatments emerge, incorporating this information into the EHR system would further enhance its value and relevance.

In conclusion, the cloud-based EHR system offers a comprehensive solution to the challenges posed by the COVID-19 pandemic, providing healthcare professionals with cutting-edge tools to respond to the crisis, deliver better patient care, and enhance public health outcomes. As the pandemic continues to evolve, such systems will play a crucial role in our global response, highlighting the importance of continued investment and research in health information technology.

Declarations.

Conflict of Interest. The authors declare no competing interests.

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Efficiency and Quality in Bottle Capping: A Comparative Analysis in the Pisco Industry

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Abstract. In the pisco industry and those dedicated to packaging liquid products, the capping process is crucial to maintaining product quality during distribution and subsequent sale. This study applied the Six Sigma methodology to evaluate process quality, followed by validation using the Analytic Network Process (ANP) through the "Super Decisions" software. This combined analysis aids in decision-making for process controls. Experimentally, a 20% improvement in capping efficiency and a 15% reduction in closure defects were achieved . Additionally, a 10% reduction in cycle time and a 25% optimization in resource usage were observed. These results highlight the effectiveness of integrating Six Sigma and ANP methodologies to enhance the capping process quality in the pisco industry. The application of these methodologies provides tangible benefits, including increased operational efficiency and improved customer satisfaction. The findings suggest that such an integrated approach can serve as a valuable framework for other industries aiming to optimize their packaging processes and achieve similar gains in product quality and process efficiency.

Keywords: Six Sigma Methodology · Analytical Network Process · Multicriteria Decision Making · Process Decision Making

1 Introduction

Bottle capping in the packaging process is a critical control point (CCP) due to the influence of various variables on capping quality.Six Sigma is defined as a tool for measuring and improving quality, data-driven and aimed at achieving perfection. Its objective is to improve processes by reducing defects to 3.4 per million opportunities [1]. However, given the multivariable nature of the factors affecting capping quality, this methodology is complemented by the application of the Analytic Network Process (ANP) methodology. ANP′s approach allows for the comprehensive consideration of the various factors influencing the process [2].

Decision-making in complex environments has become more challenging due to the increase in variables and constant changes in operational scenarios. Multicriteria methodologies have emerged as a response to this complexity, offering tools to address these challenges. The Analytic Hierarchy Process (AHP) stands out for its ability to break

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down complex decisions into simpler ones, thereby facilitating problem understanding and resolution [3].

AHP analyzes the factors involved in decision-making without the need for a common scale, making it a widely used technique for solving socioeconomic problems by considering social, cultural, and other non-economic aspects (5).

On the other hand, the Analytic Network Process (ANP) is a generalization of AHP. It allows for greater interaction between elements, both within and outside clusters, thereby facilitating a more realistic modeling of problems [5].

By allowing the evaluation of multiple relationships and the weighting of interrelationships, ANP promotes a continuous improvement approach in business models. [6]. The combination of Six Sigma and ANP in the bottle capping process at an alcoholic beverage packaging company aims to analyze and propose decision factors based on real data to reduce defects and improve production.

In the company under study, defects were identified in materials, machinery, measurement errors, incorrect adjustments, and other issues. To address this challenge, the application of the Six Sigma methodology is proposed, given its ability to enhance operational efficiency and reduce unnecessary costs by eliminating waste and optimizing processes [7].

By improving quality standards and reducing waste and variations in production processes, the company can decrease costs associated with these issues, such as unproductive work hours and rework. Additionally, higher quality leads to greater customer satisfaction, which can result in increased revenue and improved market share.

1.1 Literature Review

The literature aims to reduce defects and waste in manufacturing processes through the implementation of Six Sigma. [8–10]. They also highlight the importance of adopting systematic and data-driven approaches for continuous improvement in the manufacturing industry [7, 11]. The combination of Lean tools, such as value stream mapping and waste elimination, with Six Sigma methodologies for variability reduction, has proven to be an effective strategy for optimizing processes, increasing product quality, and meeting customer demands more efficiently [1, 12]. Additionally, the identification and elimination of sources of variability and errors are critical aspects for improving product quality and reducing operational costs [10]. It is in this context that the literature integrates practices in business operations with Six Sigma [7].

ANP considers the dependencies between elements of the defined hierarchy, reflecting interconnection and mutual influence between different criteria, sub-criteria, and alternatives in a business model [6]. However, it is necessary to develop these elements correctly and ensure consistency in the evaluation of criteria, as this evaluation helps prevent biases and erroneous decisions [13].

The importance of using rigorous mathematical approaches to address the complexity of decision-making in uncertain environments has been defined [3]. By considering this scientific approach in decision-making, it helps avoid falling into subjective practices or manipulating information without solid foundations. [4]. On the other hand, the combination of Six Sigma and ANP provides a robust framework for project selection, optimizing the use of limited resources and maximizing the impact of initiatives [14],

which is reinforced considering that the combination of ANP and DEMATEL allows effective prioritization of Six Sigma projects [15].

Given the points above and the context of the present study, we can reinforce the idea that the successful implementation of corrective actions based on data analysis and quality management strengthens the value of adopting systematic approaches for continuous improvement in industrial settings [16].

2 Methodology

The Methodology to be used is divided into 5 phases (Fig. 1):

Fig. 1. Phases Research methodology

1. Literature review of Six Sigma Continuous Improvement processes and their applicability in the bottling industry, as well as the application of the Multicriteria Decision Model (ANP), and its correlation in the development of decision-making according to management models and continuous improvement.
2. Data collection and defect detection in the Pisco Company, in the packaging process and bottle capping operation, distributed according to the data in Table 1.

Table 1. Analyzed Sample

Format	Period		Sample Size
	Start	End	
30 x 35 1000 cc.	Jan-22	Apr-23	2.900
30 x 35 700 cc.	Jan-22	Apr-23	10.424
30 x 35 350 cc.	Jan-22	Apr-23	1.792

3. Quantification of product rejections online and Finished Product holds, both in the production process and at the client and commercial levels.
4. Evaluation of the applicability of Six Sigma and ANP methodologies to reduce the rejection and hold rates due to defects and damages in the bottle capping process.
5. The application and use of the software SuperDecisions™ allow the implementation of the ANP methodology to make decisions and guide the approach that the alcoholic beverage packaging company should apply to improve the quality of bottle capping.

3 Results

This study is based on the evaluation of the capping process for pisco products using aluminum screw caps with an internal polymer seal to maintain the quality, taste, and aroma of the contents. It is estimated that this study is also applicable to the packaging of other mass-produced products with similar characteristics, such as soft drinks and other beverages.

The primary interest is to initially apply the evaluation using the Six Sigma methodology [17] and then confirm or reject the obtained results by applying the ANP methodology [3].

3.1 Six Sigma Analysis

The sample determines the Process Efficiency (Yield) [17]. The Sigma level of the process is related to this, as shown in Table 2. For this purpose, the analysis is subdivided considering the following parameters:

1. Format.
2. Production Line.
3. Closing Torque.
4. Opening Torque.

Additionally, the following defect opportunities are considered for the analysis:

1. Closing and/or opening torque greater than specified.
2. Closing and/or opening torque less than specified.
3. Deformed container neck.
4. Deformed container neck.
5. Deformed cap.
6. Cap out of specifications (size, diameter, shape, etc.).
7. Miscalibrated capping heads.
8. Damaged capping heads.
9. Height adjustment of cappers.

Below are the results obtained from the analysis of the capping head, production line, and family in closing torque (Tables 2, 3, 4, and 5) using the Six Sigma methodology [9, 16].

The results in Table 2 show a high variability in closing results, especially in larger formats (700cc and 1000cc). The Sigma levels range between 3.4 and 3.7, and the DPMO (Defects Per Million Opportunities) oscillate between 14 and 35, indicating a significant need to improve process control to reduce the defect rate and increase consistency.

The opening results in Line 1 (Table 3) also show high variability. The Sigma levels range between 3.3 and 3.6, and the DPMO (Defects Per Million Opportunities) oscillate between 15 and 36. The yield is relatively high, but the Sigma levels and DPMO indicate a need to improve process consistency to reduce the number of defects and ensure better product quality.

Line 2 shows much more consistent closing results (Table 4), with high Sigma levels (between 5.8 and 6.0) and low DPMO (between 3.4 and 6.0). This indicates a

Table 2. Closing Torque per Head Line 1 Format 30x35 (350cc,700cc, 1000cc)

Head	Yield % (350cc)	Sigma Level (350cc)	DPMO (350cc)	Yield % (700cc)	Sigma Level (700cc)	DPMO (700cc)	Yield % (1000cc)	Sigma Level (1000cc)	DPMO (1000cc)
1	98.0%	3.6	20	97.0%	3.5	30	96.5%	3.4	35
2	98.5%	3.7	15	97.3%	3.6	27	96.8%	3.5	32
3	98.2%	3.6	18	97.1%	3.5	29	96.6%	3.4	34
4	98.6%	3.7	14	97.4%	3.6	26	96.9%	3.5	31
5	98.3%	3.6	17	97.2%	3.5	28	96.7%	3.4	33
6	98.1%	3.6	19	97.0%	3.5	30	96.5%	3.4	35
7	98.4%	3.7	16	97.3%	3.6	27	96.8%	3.5	32
8	98.2%	3.6	18	97.1%	3.5	29	96.6%	3.4	34
9	98.5%	3.7	15	97.4%	3.6	26	96.9%	3.5	31
10	98.0%	3.6	20	97.0%	3.5	30	96.5%	3.4	35

Table 3. Opening Torque per Head, Line 1 Format 30x35 (350cc,700 cc, 1000 cc)

Head	Yield % (350cc)	Sigma Level (350cc)	DPMO (350cc)	Yield % (700cc)	Sigma Level (700cc)	DPMO (700cc)	Yield % (1000cc)	Sigma Level (1000cc)	DPMO (1000cc)
1	98.1%	3.5	19	97.1%	3.4	29	96.4%	3.3	36
2	98.4%	3.6	16	97.2%	3.5	28	96.7%	3.4	33
3	98.3%	3.5	17	97.0%	3.4	30	96.5%	3.3	35
4	98.5%	3.6	15	97.3%	3.5	27	96.8%	3.4	32
5	98.2%	3.5	18	97.1%	3.4	29	96.6%	3.3	34
6	98.0%	3.5	20	97.0%	3.4	30	96.4%	3.3	36
7	98.4%	3.6	16	97.2%	3.5	28	96.7%	3.4	33
8	98.3%	3.5	17	97.0%	3.4	30	96.5%	3.3	35
9	98.5%	3.6	15	97.3%	3.5	27	96.8%	3.4	32
10	98.1%	3.5	19	97.1%	3.4	29	96.4%	3.3	36

well-controlled process with less variability and fewer defects, which is essential for maintaining high product quality.

The opening results in Line 2 (Table 5) are also consistent, with high Sigma levels (between 5.1 and 5.3) and low DPMO (between 70 and 90 for 350cc, and as low as 8.5 for 1000cc). This reflects a well-controlled process with minimal variations, ensuring high quality and meeting consumer expectations.

These analyses underline the importance of controlling variability in each line to maintain consistency and quality of the final product. Line 2 demonstrates better overall performance compared to Line 1, indicating more effective quality control practices.

Table 4. Closing Torque per Head, Line 2 Format 30x35 (350cc,700cc, 1000cc)

Head	Yield % (350cc)	Sigma Level (350cc)	DPMO (350cc)	Yield % (700cc)	Sigma Level (700cc)	DPMO (700cc)	Yield % (1000cc)	Sigma Level (1000cc)	DPMO (1000cc)
1	100.0%	6.0	3.4	99.6%	4.2	4	99.2%	4.0	6
2	99.9%	5.9	5.0	99.5%	4.1	5	99.1%	3.9	7
3	99.9%	6.0	4.0	99.6%	4.2	4,5	99.3%	4.0	6,5
4	99.8%	5.8	6.0	99.4%	4.0	5,5	99.0%	3.8	8

Table 5. Opening Torque per Head, Line 2 Format 30x35 (350cc,700cc, 1000cc)

Head	Yield % (350cc)	Sigma Level (350cc)	DPMO (350cc)	Yield % (700cc)	Sigma Level (700cc)	DPMO (700cc)	Yield % (1000cc)	Sigma Level (1000cc)	DPMO (1000cc)
1	99.9%	5.3	70	99.4%	4.1	6	99.8%	4.0	8
2	99.8%	5.2	80	99.3%	4.0	6,5	99.7%	3.9	8,5
3	99.9%	5.3	75	99.4%	4.1	6,25	99.8%	4.0	8,25
4	99.7%	5.1	90	99.2%	4.0	7	99.6%	3.8	8,5

3.2 ANP Analysis

After applying Six Sigma, we identified key clusters and nodes for the decision process analysis (Table 6). The first step in our methodology is to gather information and group elements into clusters. The decision problem includes:

- **Cluster "Production Line":** The company has two production lines, Line 1 and Line 2, with different levels and machines. The nodes are Line 1 and Line 2.
- **Cluster "Product Format":** Bottle formats vary in cubic capacity, sharing the same neck. Nodes: 1000cc Format, 700cc Format, 350cc Format.
- **Cluster "Capping Analysis":** We use opening and closing torques provided by suppliers to measure capping quality. Nodes: Opening Torque and Closing Torque.
- **Cluster "Capping Issues":** Through cause-effect analysis, we identified height adjustments in the capping machine, rollers in the heads, defects in the bottle neck, and incorrect cap thickness. Nodes: Capping Height Adjustment, Capper Head Knurling Adjustment, Defective Bottle Neck, Incorrect Cap Thickness.

Once all network elements such as the objective, criteria, clusters, and alternatives are defined (Fig. 2), the decision problem is modeled using the "SuperDecisions™" software. This process involves entering all clusters and nodes into the software (Fig. 3).

Subsequently, the priorities between the elements are calculated based on those indicated by Saaty [3], to obtain the supermatrices starting from the decision problem′s unweighted supermatrix. During this stage, the elements with the greatest influence are identified, and the Saaty scale is used to measure their relative importance [18].

Table 6. Nodes & Clusters

Clúster	Nodes	Abbreviation
Capín Issues	Capper Height Adjustment	AAT
	Capper Head Knurling Adjustment	AMCT
	Defective Bottle Neck	BBD
	Incorrect Cap Thickness	ETI
Capped Analyte	Opening Torque	TA
	Opening Torque	TC
Product Format	350 cc	350 cc
	700 cc	700 cc
	1000 cc	1000 cc
Production Line	Line 1	L1
	Line 2	L2

It is essential to verify the consistency of the pairwise comparisons, which is done using the "SuperDecisions™" software. The consistency ratio must be less than 10% for the pairwise comparison matrix to be considered consistent [13]. The pairwise comparisons between the influential elements are presented in Fig. 2 as an illustrative example.

To evaluate the priorities in the Analytic Process and assign the Saaty scale, a pairwise comparison questionnaire is used. This questionnaire consists of two elements, X and Y, where it asks which of the two elements has greater influence and to what extent. This process is exemplified in Fig. 1 for better understanding.

Once all comparisons are completed and it is verified that the consistency ratio is less than 0.1, we extract the Unweighted Supermatrix, the Weighted Supermatrix, and the Limit Supermatrix. These matrices provide the final priorities of the model.

In the Unweighted Supermatrix (Table 7), the criteria are compared pairwise and assigned a relative importance value. A matrix is then generated that shows all comparisons and the values assigned. This Supermatrix is composed of column vectors, which are the priorities obtained by comparing the nodes of a cluster with respect to a main node. Each column must sum to 1 for the Supermatrix to converge to the Limit Supermatrix, making all the columns stochastic [19].

The Weighted Supermatrix (Table 8) is obtained by multiplying all the elements of a component of the Unweighted Supermatrix by the weight of the corresponding group [19].

The Limit Supermatrix (Table 9) is obtained by raising the Weighted Supermatrix to powers and multiplying it by itself. That is, when the column of numbers is the same for all columns, the Limit Supermatrix is obtained, and the matrix multiplication process stops. The Limit Supermatrix for the analyzed model is shown in the following table.

Once all the Supermatrix are obtained, the priorities provided by the model can be analyzed, and based on this, proposals for approaches can be generated for the Alcoholic Beverage Packaging Company. The priorities provided by the model are presented in Table 10.

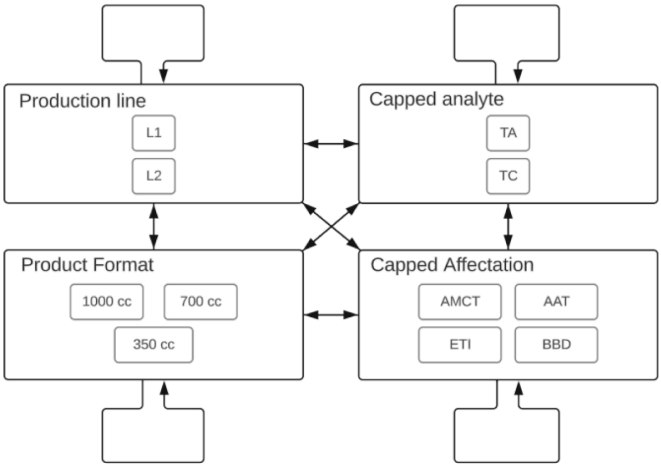

Fig. 2. Network Structure Analysis for Bottle Closure Quality

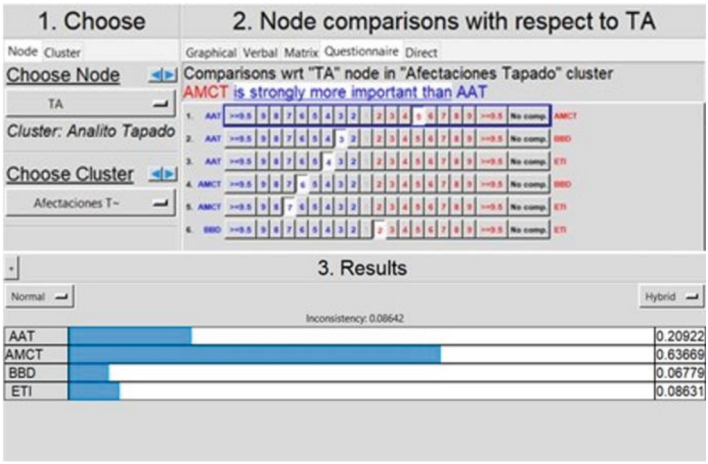

Fig. 3. Paired Comparison Questionnaire Example in Super Decisions

The results of the Six Sigma analysis on the production line provide a clear view of process performance. A comparative analysis of production lines 1 and 2 is presented below, highlighting the levels of performance, Sigma, and DPMO, identifying critical areas for continuous improvement and defect reduction. In addition, the findings of the ANP analysis are included, which help to prioritize the focus areas defined in Six Sigma to improve the quality of the capping and guide the company in making strategic decisions in a way that optimizes its production processes.

Table 7. Unweighted Super Matrix

Cluster Node Labels		Capping Issues				Capped Analyte		Product Format			Production Line	
		AAT	AMCT	BBD	ETI	TA	TC	350 cc	700 cc	1000 cc	L1	L2
Capping Issues	AAT	0	0,78377	0,19907	0,19907	0,20922	0,20906	0,25155	0,17321	0,17382	0,20554	0,2524
	AMCT	0,76116	0	0,73338	0,73338	0,63669	0,66515	0,53508	0,69148	0,69092	0,66814	0,50232
	BBD	0,07261	0,0813	0	0,06754	0,06779	0,05235	0,08049	0,05611	0,05324	0,05015	0,10188
	ETI	0,16623	0,13493	0,06754	0	0,08631	0,07345	0,13288	0,07919	0,08201	0,07618	0,1434
Capped Analyte	TA	0,1	0,1	0,1	0,1	0	100.000	0,1	0,1	0,11111	0,1	0,14286
	TC	0,9	0,9	0,9	0,9	1	0	0,9	0,9	0,88889	0,9	0,85714
Product Format	350 cc	0,06434	0,06226	0,06703	0,07193	0,12196	0,0668	0	0,1	1	0,05844	0,07796
	700 cc	0,23704	0,28508	0,27178	0,27895	0,31962	0,29256	0,14286	0	0,88889	0,29657	0,2872
	1000 cc	0,69861	0,65266	0,6612	0,64912	0,55842	0,64064	0,85714	0,9	0	0,64498	0,63484
Production Line	L1	0,88889	0,9	0,88889	0,88889	0,85714	0,9	0,75	0,88889	0,88889	0	1
	L2	0,11111	0,1	0,11111	0,11111	0,14286	0,1	0,25	0,11111	0,11111	1	0

Table 8. Weighted Super Matrix

Cluster Node Labels		Capping Issues				Capped Analyte		Product Format			Production Line	
		AAT	AMCT	BBD	ETI	TA	TC	350 cc	700 cc	1000 cc	L1	L2
Capping Issues	AAT	0	0,36238	0,09204	0,09204	0,02808	0,02806	0,01631	0,01123	0,01127	0,04453	0,05468
	AMCT	0,35192	0	0,33908	0,33908	0,08547	0,08929	0,03469	0,04483	0,0448	0,14475	0,10883
	BBD	0,03357	0,03759	0	0,03123	0,0091	0,00703	0,00522	0,00364	0,00345	0,01087	0,02207
	ETI	0,07686	0,06238	0,03123	0	0,01159	0,00986	0,00861	0,00513	0,00532	0,0165	0,03107
Capped Analyte	TA	0,03302	0,03302	0,03302	0,03302	0	0,59492	0,02454	0,02454	0,02726	0,05273	0,07533
	TC	0,29716	0,29716	0,29716	0,29716	0,59492	0	0,22081	0,22081	0,21809	0,47456	0,45196
Product Format	350 cc	0,00632	0,00611	0,00658	0,00706	0,00875	0,00479	0	0,02271	0,02523	0,00542	0,00723
	700 cc	0,02327	0,02799	0,02668	0,02739	0,02293	0,02099	0,03244	0	0,20184	0,02752	0,02664
	1000 cc	0,06859	0,06408	0,06492	0,06373	0,04006	0,04596	0,19463	0,20436	0	0,05984	0,0589
Production Line	L1	0,09714	0,09836	0,09714	0,09714	0,17066	0,17919	0,34706	0,41134	0,41134	0	0,16329
	L2	0,01214	0,01093	0,01214	0,01214	0,02844	0,01991	0,11569	0,05142	0,05142	0,16329	0

Table 9. Limit Matrix

Cluster Node Labels		Capping Issues				Capped Analyte		Product Format			Production Line	
		AAT	AMCT	BBD	ETI	TA	TC	350 cc	700 cc	1000 cc	L1	L2
Capping Issues	AAT	0,06754	0,06754	0,06754	0,06754	0,06754	0,06754	0,06754	0,06754	0,06754	0,06754	0,06754
	AMCT	0,11046	0,11046	0,11046	0,11046	0,11046	0,11046	0,11046	0,11046	0,11046	0,11046	0,11046
	BBD	0,01398	0,01398	0,01398	0,01398	0,01398	0,01398	0,01398	0,01398	0,01398	0,01398	0,01398
	ETI	0,02215	0,02215	0,02215	0,02215	0,02215	0,02215	0,02215	0,02215	0,02215	0,02215	0,02215
Capped Analyte	TA	0,19637	0,19637	0,19637	0,19637	0,19637	0,19637	0,19637	0,19637	0,19637	0,19637	0,19637
	TC	0,2947	0,2947	0,2947	0,2947	0,2947	0,2947	0,2947	0,2947	0,2947	0,2947	0,2947
Product Format	350 cc	0,00779	0,00779	0,00779	0,00779	0,00779	0,00779	0,00779	0,00779	0,00779	0,00779	0,00779
	700 cc	0,03322	0,03322	0,03322	0,03322	0,03322	0,03322	0,03322	0,03322	0,03322	0,03322	0,03322
	1000 cc	0,05557	0,05557	0,05557	0,05557	0,05557	0,05557	0,05557	0,05557	0,05557	0,05557	0,05557
Production Line	L1	0,15374	0,15374	0,15374	0,15374	0,15374	0,15374	0,15374	0,15374	0,15374	0,15374	0,15374
	L2	0,04449	0,04449	0,04449	0,04449	0,04449	0,04449	0,04449	0,04449	0,04449	0,04449	0,04449

3.3 Six Sigma

The results for Line 1, based on Process Performance and its Sigma Level, can be summarized as follows in general terms:

- **Line 1 Format 30 x 35 350cc:** With a yield of 98.32% and a Sigma Level of 3.6, 1.68% of the products are defective, generating a DPMO of approximately 17,800 defective units per million produced. A Sigma Level of 3.6 indicates moderate quality, close to acceptable.
- **Line 1 Format 30 x 35 700cc:** This line has a yield of 97.27% and a Sigma Level of 3.4. With 2.73% of the products being defective, this results in a DPMO of approximately 28,700 defective units per million produced. A Sigma Level of 3.4 indicates relatively low quality due to high variability.

Table 10. Model Priorities for each Cluster – Node

Clúster	Nodes	Normalized By Cluster	Limiting
Capping Issues	AAT	0,31543	0,06754
	AMCT	0,51585	0,11046
	BBD	0,06526	0,01398
	ETI	0,10345	0,02215
Capped Analyte	TA	0,39989	0,19637
	TC	0,60011	0,2947
Product Format	350 cc	0,08069	0,00779
	700 cc	0,34394	0,03322
	1000 cc	0,57538	0,05557
Production Line	L1	0,77557	0,15374
	L2	0,22443	0,04449

- **Line 1 Format 30 x 35 1000cc:** For this line, the yield is 96.61% and the Sigma Level is 3.3. With 3.39% of the products having closure defects, the DPMO reaches 35,900 defective units per million produced. A Sigma Level of 3.3 indicates very low quality due to high variability.

All the above is summarized in Table 11:

Table 11. Closing Torque Results

Line / Product	Yield %	Sigma Level	Defects per Million
L1 / 350 cc	98,32%	3,6	17.800
L1 / 700 cc	97,27%	3,4	28.700
L1 / 1000 cc	96,61%	3,3	35.900
L2 / 350 cc	100,00%	6	3,4
L2 /700 cc	99,59%	4,1	4.660
L2 / 1000 cc	99,30%	4	6.210

Applying the same analysis to Line 02, the following can be indicated:

- **Line 2 Format 30 x 35 350cc**: With a yield of 100% and a Sigma Level of 6, this line has no defective products, resulting in a DPMO of 3.4 units per million produced, maintaining an optimal level of quality.
- **Line 2 Format 30 x 35 700cc:** With a yield of 99.59% and a Sigma Level of 4.1, only 0.41% of the products will be defective, generating a DPMO of 4,660 defective units per million produced. The high quality of the process should be maintained or improved with control tools.

- **Line 2 Format 30 x 35 1000cc:** With a yield of 99.30% and a Sigma Level of 4.0, only 0.70% of the production is defective, generating a DPMO of 6,210 units per million produced. The high quality of production should be maintained or improved with appropriate process control measures.
- **Line 1 Format 30 x 35 350cc:** With a yield of 99.90% and an average Sigma Level of 5.3, only 0.10% of the production will be defective regarding container opening, generating a DPMO of 70 units per million produced. The high quality of production should be maintained and improved.
- **Line 1 Format 30 x 35 700cc:** With a yield of 99.33% and a Sigma Level of 4.0, 0.67% of the production will be defective, generating a DPMO of 6,210 defective units per million. The high quality of the process should be maintained or improved with appropriate control measures.
- **Line 1 Format 30 x 35 1000cc:** With a yield of 99.8% and a Sigma Level of 3.9, only 0.82% of the production will be defective, generating 8,190 defects per million opportunities. The high quality of the process and low variability should be maintained.

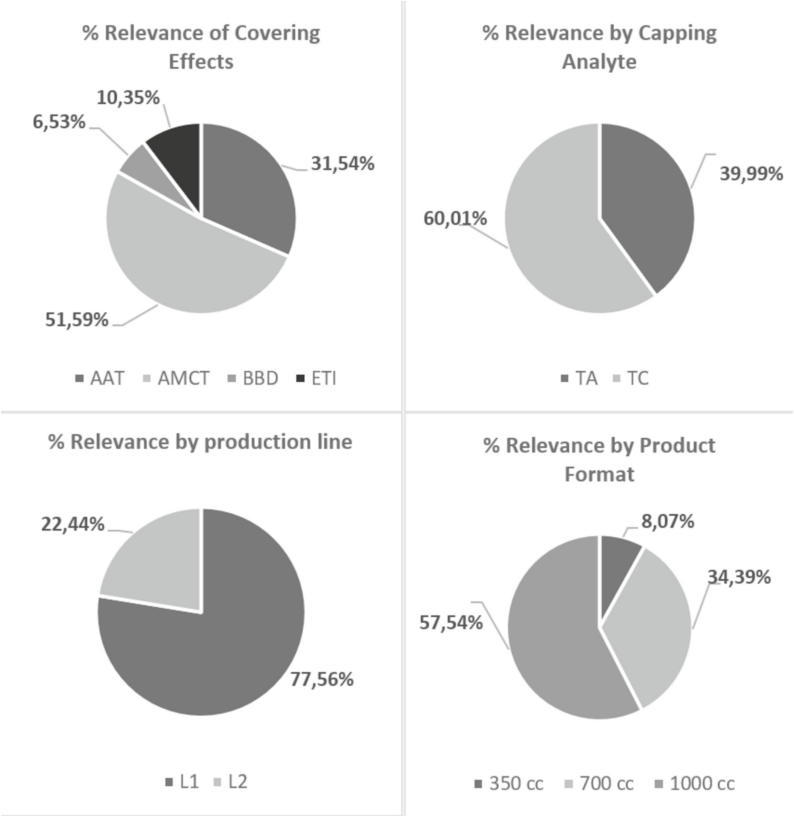

Fig. 4. Order of priorities and importance for each Node in the Cluster

The company should focus on Line 1, as it shows low sigma levels, indicating high process variability and a high probability of defective products, especially in container closures. This trend also repeats in the opening process.

On the other hand, Line 2 performs better, with several products reaching a sigma level of 6.0. However, defective products still represent 11.7% of total production, compared to 88.3% in Line 01. This highlights the need to improve quality standards in Line 1 to reduce defective products and ensure greater efficiency in the production process.

3.4 Anp

From Table 13, we can organize the data by percentage and consequently determine and propose to the Alcoholic Beverage Packaging Company where it should focus its efforts to improve the capping quality of its products. Based on this, we can graph the order of priorities and the importance of each node within the cluster in which it is categorized (Fig. 4).

4 Conclusions

Integrating Six Sigma methodologies and the Analytical Network Process (ANP) provided significant production advantages within the pisco industry. Six Sigma improved quality by identifying and eliminating defects, using a data-driven approach to reduce process variability. This resulted in a 20% increase in capping process efficiency and a 15% reduction in closure defects.

ANP, as a strategic tool, complemented Six Sigma by enabling the evaluation of multiple interrelated factors in the production process. It facilitated a detailed analysis of the interdependencies between process variables, empowering strategic decision-making to optimize production.

It was concluded that Line 1 was a priority for improving capping quality, representing 77.6% of importance compared to 22.4% for Line 2. Regarding product formats, the 1000 cc format presented more opportunities (58%), followed by the 700cc format (34%). Measuring capping torques, especially closing torque, was highlighted as a crucial aspect of quality control. Roller adjustments and capping machine height were key areas to address, accounting for 52% and 32% of relevance, respectively.

Combining both methodologies improved product quality, reduced cycle time by 10%, and optimized resource usage by 25%. These improvements translated into greater product consistency and increased customer satisfaction. On a global level, these improvements increased revenue and market share, strengthening the company's quality and operational efficiency reputation.

A maintenance program was proposed to standardize the process and prevent capping quality deviations, allowing operator training and improved efficiency. For future studies, it is suggested that the underlying causes of capping defects be investigated further and emerging technologies for continuous control and improvement of the packaging process explored. In addition, it would be beneficial to conduct long-term monitoring of the implementation of the proposed maintenance program and evaluate its impact on product quality and operational efficiency.

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A Mathematical Model for a Realistic Course Scheduling at Universities

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Abstract. Timetabling is a combinatorial and challenging problem in different fields where it is required to allocate scarce resources. One of the main variants is the University Course Timetabling Problem (UCTP), where courses must take a location and the academic sessions must be distributed avoiding overlapping schedules or preference conflicts. Despite the high complexity of its solution, it is increasingly necessary to include more realistic characteristics and formulate efficient models. In this paper, new realistic features focused on the development of student's curriculum are included and a mixed-integer linear programming model is proposed to address this problem. The model's objective is to maximize all teacher's preferences and reduce the overlaps between courses that can be viewed either in advance or delayed. The proposed model was validated in the timetabling in the Industrial Engineering Program at the Pontificia Universidad Javeriana Cali, Colombia. The results show an increase of 47.7% regarding the preferences of the professors, as well as a reduction of 99.37% of the time associated with the semester scheduling process and currently, the perception of students is being assessed as they progress through the semesters, with preliminary results indicating an increase in satisfaction.

Keywords: University Course Timetabling Problem · Scheduling · Mathematical Model

1 Introduction

Efficient resource allocation in educational institutions is crucial for promoting academic excellence and productivity. Within this task, one of the most important problems is the complex management of university timetabling, well-known as the Timetabling Problem (TTP). It is a complex challenge in the field of operations research that requires advanced programming techniques for its solution. Beyond its logistical challenges, the TTP has substantial implications for students' academic careers. Literature in educational psychology highlights that

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effective time allocation is vital for learning outcomes; strategies like spaced repetition and deliberate practice improve material retention and comprehension [5]. In contrast, poor time allocation, such as dense class schedules without breaks, can result in increased stress and suboptimal performance [1]. Therefore, the organization of class schedules and study periods within the timetable plays a crucial role in enhancing students' engagement with course material.

The complexity of TTP lies in managing limited resources like classrooms and time slots to meet diverse academic requirements. Fundamental constraints in TTP include hard constraints, mandatory for solution validity, and soft constraints, representing preferences. Some of the main variants include High-School Timetabling Problem (HTTP), University Course Timetabling Problem (UCTP), and University Examination Timetabling (ETTP), each with its own constraints and objectives. Despite its seemingly straightforward nature, current models of large-scale realistic problems could not be viable for solving them in a short time. The operations research field offers two main solution approaches: exact techniques, that guarantee an optimal solution but with a high consumption of computational effort, and approximate techniques, such as metaheuristics, which prioritize computation time over precision. However, linear programming can be effective for smaller-scale instances.

This paper focuses on the UCTP by incorporating new realistic elements aimed at students' curriculum development, specifically tailored for Pontificia Universidad Javeriana Cali (PUJ) in Colombia. This research considers the likelihood of course repetition or advancement as a decision factor, a concept that is rarely explored in the literature. The proposed model leverages statistical data to make assignments, providing students with opportunities to advance in their courses or retake classes they have failed. To solve it, a mixed-integer linear programming (MILP) model is proposed that aims to maximize professors' preferences while minimizing overlaps between courses, thereby improving scheduling efficiency. Validation within PUJ's Industrial Engineering Program revealed a 47.7% increase in professor preferences and a 99.37% reduction in semester scheduling time compared to previous solutions. Preliminary student feedback indicates increased satisfaction, demonstrating the practical relevance of this approach in addressing real-world timetabling challenges. Additionally, the framework can be adapted for other academic institutions facing similar scheduling issues.

The remainder of the paper is organized as follows. Section 2 presents the definition of the problem addressed. Section 3 provides a literature review of existing methods to address this problem. Subsequently, the mathematical formulation is presented in Sect. 4. Section 5 describes the computational experiments. Finally, a summary and some concluding remarks appear in Sect. 6.

2 Description of the Problem

The UCTP consists of efficiently allocating events as courses, professors, and students to a fixed number of time slots and rooms in academic institutions,

subject to various constraints. Some common features of these problems include room capacity, instructor availability, student preferences, and avoiding conflicts between courses. The main objective of UCTP is to create a timetable that optimizes the utilization of resources, minimizes scheduling conflicts, and satisfies the preferences and constraints imposed by the educational institution.

This work focuses on adapting the University Course Timetable Planning (UCTP) system to the specific context of Pontificia Universidad Javeriana Cali (PUJ) in Colombia. At PUJ, the process of students enrolling in classes begins with faculty meticulously planning course offerings based on historical demand, classroom allocations, and class schedules. Approximately a month before each semester, students access the university's online portal to register for classes, where they can view recommended course plans while retaining the flexibility to adjust based on personal preferences and commitments. Currently, PUJ lacks a standardized method for organizing semester schedules, leading to manual processes and inefficiencies, requiring around 80 h per semester. This manual approach, managed by individual faculties, focuses on factors like course demand, scheduling, and classroom availability. However, difficulties arise in accurately estimating demand and classroom availability, posing challenges in scheduling courses. This study specifically addresses the Industrial Engineering Program (IEP) within the Engineering and Science Faculty at PUJ. The PUJ's academic structure incorporates several key attributes: consistent lecture timing with a stable weekly schedule for the entire semester, sufficient general-purpose classrooms, a student-driven schedule customization system accommodating diverse preferences and course combinations, and standardized class durations of 2 or 3 hours within a 7:00 a.m. to 9:00 p.m. timeframe. These specific characteristics of PUJ addressed in this problem can be generalized and adapted to other educational institutions that share similar operational characteristics.

The addressed problem includes features of the course assignment that can be classified into two groups: common characteristics discussed in the literature and new proposed characteristics focused on the student. The first group is shown below:

- **Number of weekly sessions for each course:** The weekly intensity of the courses depends on the credits associated with the curriculum. Within the PUJ, the courses have intensity of one, two or three times a week.
- **Duration of class session per course:** The faculty determines the duration of the sessions of two or three hours. This depends on the theoretical or practical intensity of the Course.
- **Room requirements for each course:** Each course has spatial requirements according to the topics addressed; it may require the industrial engineering laboratory, a computer room, a regular classroom, or the room 3.6 which is the industrial engineering computer laboratory. Some courses can be taught in more than one type of room.
- **Set of courses per semester:** The courses per semester are determined by the engineering faculty. These are sets of courses that can be enrolled

according to the curriculum, however, it is not strictly necessary to adhere to this curriculum.

- **Availability of teachers by course:** Professors at PUJ are assigned a fixed class schedule each semester, which aligns with the students' schedules. Classes are allocated from Monday to Friday between 7:00 a.m. and 9:00 p.m., and this schedule repeats without variation throughout the semester. Due to the repetitive nature of this schedule, professors must declare their weekly available and unavailable hours to the faculty. This declaration is vital to identify when professors are available to teach and which times are blocked and cannot be scheduled for them. This depends on the professor's availability, space, and personal schedules (lunch, faculty meetings).
- **Professor preferences:** Professors may have specific preferences regarding their teaching schedules throughout the week. For instance, a professor might enjoy teaching on Mondays at 7:00 a.m. but dislike teaching on Fridays at 4:00 p.m. These preferences indicate when professors would ideally like to teach or avoid teaching, but they are not as strict as availability requirements and can be overridden. Therefore, professors might find themselves assigned classes during their non-preferred hours or not assigned classes during their preferred times. While the university considers professors' preferences, they are not mandatory and cannot be guaranteed.

The second group of features of the proposed approach introduces a novel perspective by emphasizing two distinct factors not typically explored in the literature: the set of courses likely to be repeated and those likely to be advanced. These are described below:

- **Set of Courses Likely to be Repeated:** In traditional UCTP formulations, the primary focus is on optimizing the allocation of courses, professors, and classrooms for a single semester, overlooking the potential for course repetition. However, in many academic institutions, certain courses exhibit higher rates of failure or cancellation, requiring their repetition in subsequent semesters. By identifying and prioritizing these courses prone to repetition, our model effectively anticipates and addresses future scheduling challenges. This predictive capability enhances the resilience of the timetable generated, minimizing disruptions over multiple semesters.
- **Set of Courses Likely to be Advanced:** Another fundamental aspect of the proposed approach lies in its recognition of courses likely to be advanced by students. While conventional models rigidly adhere to the prescribed curriculum, this approach acknowledges the inherent flexibility in students' course selections; by identifying courses for which prerequisites are fulfilled and which students may opt to take earlier than scheduled. In this way, the scheduling efficiency by strategically allocating resources to meet evolving demand is optimized.

3 Literature Review

De Werra was one of the first authors to address the idea of preassignments and he makes a distinction between test and course scheduling, emphasizing the various optimization goals and constraints related to each [9]. Werra starts by outlining a basic model that forms the basis for timetabling issues. Since then, this problem has been investigated from different perspectives, including institution-specific characteristics (as the UCTP), formulation of mathematical models, exact solution methods, multi-objective approaches, and the development of metaheuristics for large-scale problems. Below, the most recent and relevant research regarding the UCTP is described.

Crobu, Di Francesco, and Gorgone introduced a new variant of UCTP, the Italian high school timetabling Problem [3], proposing problem-specific attributes such as equal downtime allocation for teachers, workload balance, and avoiding multiple lessons for each class in a single day. The authors present an Integer Programming model executed in two phases, first allocating teachers to different time slots, followed by the assignment of courses to teachers. With a different approach by prioritizing human factors, Mohd Zaulir et al. examine human preferences, introducing a preference data-driven mathematical model for optimizing university course scheduling [7]. The model efficiently arrives at an optimal solution within approximately 22 minutes, corresponding to 97.5% of the ideal value. Moreover, 91.8% of courses align with the most preferred time slots and locations. This study underscores the significance of integrating human preferences into university course scheduling models, offering valuable insights to optimize schedules in alignment with stakeholders' inclinations and demands. Daskalaki et al. focused on formulating a general integer programming model tailored to address the university timetabling problem [4]. It is a comprehensive approach that establishes general constraints applicable to diverse educational institutions, carefully delineating regular classes from specialized laboratory sessions to prevent scheduling conflicts. In addition, the authors categorized courses into mandatory and elective, forming the basis for robust hard and soft constraint formulation. The research also factored in human resource availability.

Reviewed papers show that these models are practical and effective in achieving optimal solutions with real-size problems within reasonable computational times. On the other hand, there are iterative approximation methods as metaheuristic algorithms, that are very time-efficient and scalable to large problems. While exact methods guarantee finding an optimal solution, at the cost of significant computational effort, metaheuristics sacrifice precision for reduced computing time [8]. The main research direction in this problem aims to include more realistic elements in the models, although this increases their complexity. This is justified by the fact that each university has particular elements that make it a unique case. On the other hand, it is also relevant to consider scheduling from the student's point of view, as it is truly the student who experiences the educational process.

4 Proposed Approach

This study proposes a mathematical model aimed at effectively assigning all courses without creating any hard overlaps while optimizing the satisfaction of teachers' preferences and minimizing soft conflicts. Despite the problem's NP-Hard complexity, the model is deemed appropriate due to the prevalence of real-world problems of small to medium size that can be optimally addressed using exact methodologies. The section outlines the assumptions made and elaborates on the components of the mixed integer linear programming model, including sets, parameters, variables, the objective function, and constraints.

Based on the requirements and specifications of the IEP at the PUJ Cali, the following assumptions and characteristics are defined:

1. The program planning horizon spans five days a week, encompassing Monday to Friday. The schedule is the same for all weeks of the academic period.
2. There are courses with an hourly intensity of two or three hours, resulting in 11 hourly blocks, as shown in Table 1.
3. The courses have a weekly intensity defined in advance by the Faculty. The weekly intensity can be two or more days (not consecutive), and the assignment must be in the same time block of the week, but courses can only be assigned once daily.
4. All courses have a single associate teacher, however, one teacher can teach different classes.
5. Four types of classrooms are considered: computer rooms, regular classrooms, the industrial engineering laboratory, and, in particular, the Lagos 3.6 room, which is designated for the exclusive use of the IEP. The scheduling solutions should specifically prevent overlaps in the industrial engineering laboratory and the Lagos 3.6 room, as each of these rooms is unique and can only accommodate one class at a time.
6. According to the program's curriculum, each course belongs to a specific semester; courses of the same semester cannot be crossed (in schedules).
7. A set of courses that can be delayed or advanced depending on the semester was considered.

Table 1. Possible time blocks for course assignments.

Categorization	ID	Time Range	Categorization	ID	Time Range
Two hours blocks	1	7:00–9:00	Three hour blocks	7	7:00–10:00
	2	9:00–11:00		8	10:00–13:00
	3	11:00–13:00		9	14:00– 17:00
	4	14:00–16:00		10	17:00–20:00
	5	16:00–18:00		11	18:00–21:00
	6	18:00-20:00			

4.1 Integer-Mixed Linear Programming Model Proposed

Next, the sets, parameters and variables proposed were defined, followed by the objective function and the corresponding constraints.

Sets

- $D := \{1, \ldots, 5\}$: set of available days for the assignment of weekly classes.
- $B := \{1, \ldots, 11\}$: set of time blocks available for assigning courses, these correspond to those presented in Table 1.
- J_b: set of time block $b \in B$ containing the blocks with which it is incompatible.
- $INC := \{(1, 7), \ldots, (b1, b2)\}, b1, b2 \in B$: set of pairs of incompatible time blocks.
- $S := \{1, \ldots, 9\}$: set of semesters considered.
- $L := \{1, \ldots, 4\}$: set of available classrooms includes 1): Room 3, 6; 2): Industrial engineering laboratory; 3): Computer room; and 4): Regular classroom. Classrooms of type 1 and 2 are unique, so no overlapping of courses is allowed in these. In contrast, classrooms of type 3 and 4 have more generic characteristics, resulting in their supply always being higher than the demand.
- $G := \{1, 2\}$: set of possible groups related to the same course.
- $P := \{1, \ldots, 57\}$: set of professors associated with the courses of the IEP.
- $K := \{1, 2\}$: set of types of courses, these can be: 1, those that belong to a semester in the study plan, 2: those that are backward or forward and that can cross.
- M_{sk}: courses in the semester $s \in S$ of type $k \in K$. For example, M_{11} those that are courses of the first semester and belong to the same semester in the curriculum, or M_{32} those courses that in the third semester can be delayed or advanced.
- $MS_s = \bigcup_{k \in K} M_{sk}$: set of courses that can be taken in semester $s \in S$ including those that can be advanced or delayed.
- $MT := \{1, \ldots, 50\}$: set of all the courses that are found in all the semesters.

Parameters

- IS_m: weekly intensity that course $m \in MT$ is required to have.
- HB_{mb}: binary parameter that indicates if the course $m \in MT$ can be taught in the hours of the block $b \in B$. It takes the value of 1 when the course can be taught, and 0 otherwise.
- SA_{ml}: binary parameter that indicates which room or place $l \in L$ is available for each course $m \in MT$. It takes the value of 1 when the room is available, and 0 otherwise.
- PR_{mpg}: binary parameter that indicates which teacher $p \in P$, is assigned to each course $m \in MT$ in the group $g \in G$. It takes the value of 1 when assigned, and 0 otherwise.

– $Pref_{mbdg}$: contains the existing preferences for each course $m \in MT$ of the group $g \in G$, in the block $b \in B$ of the day $d \in D$. This information was obtained from direct surveys with the professors of the IEP, subsequently, the preferences of each professor were linked to their respective courses. Therefore, the preferences are directly linked to the course and group taught by each professor interviewed. Preferences were measured on a scale of 1 to 5, where 5 is the most preferred schedule. Professors from whom no response was obtained or was not considered by the IEP were assigned a neutral preference equal to 3.

Decision Variables

– X_{dbmlgp}: binary variable that takes the value of 1 if the course $m \in MT$ of the group $g \in G$ is assigned on the day $d \in D$ to the teacher $p \in P$ in the block $b \in B$ at the room $l \in L$. It is 0 if it is not assigned.
– Y_{dsb}: number of overlaps between courses that can be delayed or advanced on the day $d \in D$ with semester $s \in S$ placement in the same type of block $b \in B$.
– $W_{ds(b1)(b2)}$: number of overlaps between courses that can be delayed or advanced on the day $d \in D$ with semester $s \in S$ placement in the incompatible blocks $(b1, b2) \in INC$.

Figure 1 shows an example of Y_{dsb} and $W_{ds(b1)(b2)}$ variables, highlighting their differences. On the left side, the courses $1A$ and $13B$ have the same time blocks on the same day, this is an overlap. On the right side, courses $A1$ and $17A$ do not have the same time blocks but in fact they also correspond to an overlap between schedules.

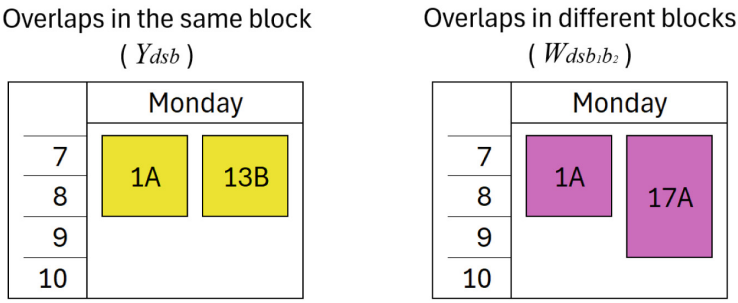

Fig. 1. Types of variables that represent overlaps.

– N_{bmg}: support binary variable that takes the value of 1 if the course $m \in MT$ of the group $g \in G$ is assigned in the block $b \in B$. This variable is used to ensure that the same course with a weekly intensity greater than or equal to 2 is taught in the same time block.

Objective Function

The objective to be maximized is the number of preferences minus the number of soft overlaps between courses that can be advanced or delayed (Eq. (1)), resulting in a multi-objective function with two evaluation criteria. Literature suggests that a common approach to these problems is to assign weights to each objective based on their relevance to stakeholders [6]. The IEP Director determined that both criteria should share the same weight in the objective function, leading to no coefficients being assigned to their importance. Conflicts of preferences among courses are resolved numerically by the model, which maximizes the objective function, resulting in preferences being assigned arbitrarily.

$$\text{maximize } z = \sum_{p\in P}\sum_{d\in D}\sum_{b\in B}\sum_{m\in MT}\sum_{g\in G}\sum_{l\in L} X_{dbmlgp} * Pref_{mbdg} - \sum_{d\in D}\sum_{s\in S}\sum_{b\in B} Y_{dsb} - \sum_{d\in D}\sum_{s\in S}\sum_{(b1,b2)\in INC} W_{ds(b1)(b2)} \quad (1)$$

Subject to

- **Daily intensity**: considering all blocks and locations on the same day a course cannot be assigned more than once (constraints (2)).

$$\sum_{l\in L}\sum_{b\in B} X_{dbmlgp} \leq 1, \qquad \forall d \in D, g \in G, p \in P, m \in MT \quad (2)$$

- **Consecutive days:** courses should not be scheduled on consecutive days since this is one of the policies within the schedules for the IEP (constraints (3)). Here, $d \in D$ varies from 1 to 5, representing days from Monday to Friday. However, it is limited to the first four days of the week to avoid $d+1$ exceeding the range.

$$\sum_{l\in L}\sum_{b\in B} X_{dbmlgp} + X_{(d+1)bmlgp} \leq 1, \quad \forall d \in \{1,2,3,4\}, g \in G, p \in P, m \in MT \quad (3)$$

- **Hourly intensity:** according to Table 1, each course corresponds to blocks of 2 or 3 hours. To differentiate the hourly intensity of each course, the HB_{mb} parameter was used, which enables the main variable to take values only in the blocks that correspond to it. The HB_{mb} parameter also allows forcing or prohibiting a course to be scheduled at a specific block, this can be useful in the case there are courses that by an external force can only be scheduled at in a specific timetable (constraints (4)).

$$X_{dbmlgp} \leq HB_{mb}, \qquad \forall d \in D, g \in G, p \in P, m \in MT, l \in L, b \in B \quad (4)$$

– **Weekly intensity:** to ensure that the assignments are made only the corresponding number of times during the week, the parameter IS_m was used together with a binary support variable, the latter for each course and group will be enabled in a single time block (constraints (5) and (6)).

$$\sum_{l \in L} \sum_{p \in P} \sum_{d \in D} X_{dbmlgp} = IS_m * N_{bmg}, \qquad \forall g \in G, b \in B, m \in MT \tag{5}$$

$$\sum_{b \in B} N_{bmg} = 1, \qquad \forall g \in G, m \in MT \tag{6}$$

– **Overlaps per Room:** Constraints (7) ensure that the main variable only takes on values allowed by the parameter SA_{ml}, while constraint (8) prevents assigning more than one lecture to conflicting rooms within the same block and day. The set J_b is used to define incompatible blocks, ensuring that overlaps are avoided in these specific restrictions.

$$X_{dbmlgp} \leq SA_{ml}, \qquad \forall d \in D, g \in G, p \in P, m \in MT, l \in L, b \in B \tag{7}$$

$$\sum_{p \in P} \sum_{g \in G} \sum_{m \in MT} \sum_{j \in J_b} X_{djmlgp} \leq 1, \qquad \forall d \in D, b \in B, l \in \{1, 2\} \tag{8}$$

– **Overlaps per Teacher:** Constraints (9) ensure that courses are assigned only to the teacher specified for the course, as defined by the parameter PR_{mgp}. Constraint (10) prevents scheduling conflicts by ensuring that no teacher is assigned to more than one course within the same block and day.

$$X_{dbmlgp} \leq PR_{mgp}, \qquad \forall d \in D, g \in G, p \in P, m \in MT, b \in B, l \in L \tag{9}$$

$$\sum_{l \in L} \sum_{g \in G} \sum_{m \in MT} \sum_{j \in J_b} X_{dbmlgp} \leq 1, \qquad \forall d \in D, p \in P, b \in B \tag{10}$$

– **Overlaps per Semester - Same Block (Hard Constraint):** Constraints (11) ensure that courses for the same semester do not overlap within the same block. If a solution cannot be found without these overlaps, the model may need to introduce a relaxation variable that permits overlaps, which should also be included in the penalized objective function.

$$\sum_{p \in P, l \in L} \sum_{g \in G} \sum_{m \in M_{s1}} X_{dbmlgp} \leq 1, \qquad \forall d \in D, s \in S, b \in B \tag{11}$$

– **Overlap Due to Overtaking or Delay - Same Block (Soft Constraints):** Constraints (12) handle overlaps between courses that may be advanced or delayed, allowing for overlaps with a penalty variable Y_{dsb} included in the objective function. These constraints address overlaps within the same time block.

$$\sum_{p \in P, l \in L} \sum_{g \in G} \sum_{m \in MS_s} X_{dbmlgp} \leq 1 + Y_{dsb}, \qquad \forall d \in D, s \in S, b \in B \tag{12}$$

– **Overlaps per Semester - Incompatible Blocks (Hard Constraints):** To complement constraint (12), constraint (13) prevents overlaps between incompatible time blocks $(b1, b2) \in INC$. It uses a set of pairs of incompatible blocks to ensure that no overlaps occur.

$$\sum_{p \in P, l \in L} \sum_{g \in G} \sum_{m \in M_{s,1}} \left(X_{d(b1)mlgp} + X_{d(b2)mlgp} \right) \leq 1, \quad \forall d \in D, s \in S, (b1, b2) \in INC \quad (13)$$

– **Overlap Due to Advancement or Delay - Incompatible Blocks (Soft Constraints):** To address soft overlaps that cannot be completely eliminated, constraints (14) consider the same incompatible blocks $(b1, b2) \in INC$ as in (13), but allow for overlaps related to courses that are advanced or delayed per semester, incorporating the variable $W_{ds(b1)(b2)}$.

$$\sum_{p \in P, l \in L} \sum_{g \in G} \sum_{m \in MS_s} \left(X_{d(b1)mlgp} + X_{d(b2)mlgp} \right) \leq 1 + W_{ds(b1)(b2)}, \quad \forall d \in D, s \in S, (b1, b2) \in INC \quad (14)$$

Figure 2 shows a general scheme of the proposed optimization model that starts with a data collection followed by the definition of the assumptions to later formulate the mathematical model, which is solved using the CPLEX solver, obtaining the result of the variables which represents the assignment of schedules for the entire academic period.

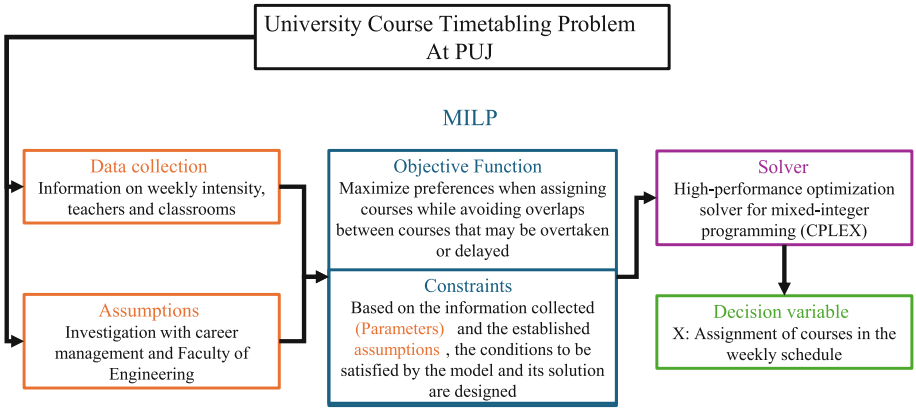

Fig. 2. General scheme of the proposed optimization model.

5 Computational Results

In this section, the results of the numerical experiments are reported and are used to validate the effectiveness of the proposed mathematical model. The experiments were run on a PC with 2.42 GHz 11th Gen Intel(R) Core(TM) i5-1135G7, and 8 GB of RAM. The mixed integer programming model is solved by using the CPLEX 22.1.1.0 solver. This section is divided into two parts: the first details the instances where the proposal will be validated, and the second shows the computational results.

5.1 Instances

Three instances with different characteristics are considered to assess performance in various scenarios and determine its behaviour: Soft, Actual, and Restricted. The current IEP case was taken as a starting point, and aspects related to hard constraints, specifically by classrooms, were modified to generate the other scenarios. The purpose is to analyze the performance of alternatives when dealing with cases with more conflicts, but without altering the number of restrictions, only the content of the SA_{ml} parameter was altered obtaining a different number of conflicts, as these directly affect the feasibility of the problem. All data relating to the instances considered in this study are available in https://github.com/NicolasVidalDuque/puj_timetabling.git.

For creating the new instances only the SA_{ml} parameter was modified, in which for the Soft scenario all the courses are assigned to classrooms type 3 and 4 in such a way that there are no conflicts; for the Restricted scenario as many courses as possible were assigned to classrooms type 1 and 2, respecting the feasibility of the problem. So each course was tested in restricted classrooms. The details of the number of courses with conflicts per classroom are shown in Table 2.

Table 2. Complexity of scenarios: courses with classroom conflicts.

Scenario	Courses with classroom conflicts	Number of hard conflicts
Soft	0(0%)	642
Actual	8(16%)	676
Restricted	14(28%)	952

The number of courses and the number of teachers were not changed to ensure that the size of the problem is not affected and that the results obtained in the objective function are comparable.

5.2 Obtained Results

Table 3 presents the results obtained after executing the model to assess its capacity to reach an optimal solution within a time limit. The first column shows the instance to be resolved, OF refers to the value of the objective function reached, Preferences and Overlaps show the number of respective occurrences in the scheduling. The limit time and execution time of the solver are also reported, as well as the status returned by CPLEX [2]. In all cases, the proposed linear programming model has 1 261 040 decision variables and 3 819 640 constraints.

Table 3. Results of the proposed model in the three generated scenarios.

Instance	OF (z)	Preferences	Overlaps	Time limit	Time execution	Status
Soft	265	563	298	1 min	60.1 s	422
	277	567	290	10 min	600.2 s	422
	278	567	289	20 min	990 s	2
Actual	216	540	324	1 min	61.5 s	422
	273	567	294	10 min	593.9 s	2
Restricted	239	547	308	1 min	60.14 s	422
	257	561	304	10 min	600.1 s	422
	257	561	304	20 min	1167.3 s	2

The results show that all instances achieved optimal outcomes within the time limit. However, as problem complexity increases, the optimal value decreases. This happens because more restrictive constraints limit the solution space, making it harder to find better solutions. Consequently, the objective function value drops due to increased conflicts, leading to tighter schedules with fewer available slots for lectures.

According to Table 3, the Restricted and Soft instances exhibit similar behavior, improving upon the initial solution. However, after 300 s of computation, the objective function value shows little significant improvement. Although higher complexity was expected to increase computation time, extreme cases-both unrestricted and highly restricted-take 67% and 97% longer than the Actual case, respectively, indicating increased complexity. Fewer constraints expand the search space, extending exploration time, while many constraints reduce the search space but make finding feasible solutions more challenging.

Finally, as an example, the distribution of one semester is illustrated in Fig. 3. The table on the left displays the courses for the same semester (highlighted in yellow), while the table on the right shows courses that can be delayed (in orange) or advanced (in green) within that semester. These delayed or advanced courses are allowed to overlap with the yellow courses but must be minimized. The figure demonstrates that courses from the same semester are scheduled to avoid any overlaps that would violate the restriction. Additionally, some overlaps between

the delayed and advanced courses are present but minimized. It is crucial to note that these overlaps are managed while avoiding conflicts with the courses in their own semester, adding complexity to their scheduling.

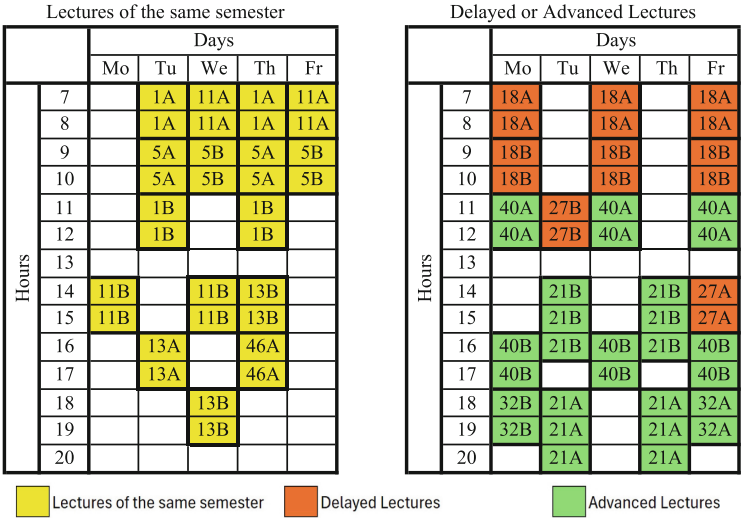

Fig. 3. A feasible example of a solution. (Color figure online)

6 Conclusions

This study addresses the University Course Timetabling Problem (UCTP), it consists of allocating courses to time slots while fulfilling several constraints, including room capacities, instructor availability, and preventing courses from running overlapping. The objective is to create schedules and allocate resources as efficiently as possible in a university setting. This study proposes a Mixed-Integer Linear Programming (MILP) model that includes two new realistic features based on students' perspectives: one is to consider courses that students are likely to repeat or fail, and the other is to include courses that students may choose to take earlier than what is required by the traditional curriculum.

The model reduces future scheduling issues over several semesters by taking repeated courses into account. It also provides a flexible approach to resource allocation by scheduling courses for advancement, which allows it to adjust to changing student needs instead of rigidly adhering to predetermined curricula. In addition to limiting overlaps, constraints maintain session intensities, prohibit back-to-back scheduling, and ensure room and instructor availability. The proposed MILP model was evaluated in a real case Pontificia Universidad Javeriana Cali (PUJ) in Colombia. Additionally, two different scenarios were generated

based on the PUJ instance: Soft and Restricted, each with of them with 0% and 28% of courses with classroom restriction. The objective is to maximize faculty preference fulfilment and minimize course overlaps. Results demonstrate that the availability of classrooms in the universities is the bottleneck, reaching the maximum of 28% of the courses that can be seen in classrooms with limited availability. It was also observed that when approaching the scenarios with fewer restrictions (Soft) or more restricted, the computation time increases, due to the need to explore a larger solution space in the first case and the difficulty of finding feasible solutions in the second. However, all scenarios converge to an optimal solution in a maximum execution time of 20 minutes.

Regarding the limitations in the implementation of the proposed model, issues related to scalability and long computation times associated with MILP are included, particularly in larger instances. While the model incorporates student perspectives, it may not fully account for all individual preferences, which could affect allocation satisfaction and efficiency. Classroom availability also poses a challenge, especially at PUJ, where physical plant limitations restrict the model's applicability. Moreover, the implementation of the model requires highly trained personnel with advanced knowledge of linear programming and technical skills, which can limit its long-term effectiveness. Future research directions include enhancing the integration of student perspectives in scheduling, exploring heuristic and metaheuristic algorithms for improved efficiency, and investigating the effects of various constraints and scenarios on scheduling outcomes to develop tailored solutions for specific university contexts.

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Linking Clinical Information to ICF: Inter- and Intra-Rater Agreement When Using a Coding Platform

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Abstract. Mapping information to the International Classification of Functioning, Disability, and Health (ICF) continues to pose a challenge for different health professionals, especially in clinical practice contexts, but tools based on information technologies might improve the efficiency of this process. In this study, we aimed to assess the agreement and efficiency of coding Specific, Measurable, Achievable, Relevant, and Timebound (SMART) therapeutic goals to ICF using a web ICF-Coding Platform (ICF-CP). Inter- and intra-rater agreement values were analyzed, both using and not using ICF-CP (stage 1), without using ICF-CP (stage 2), and only using ICF-CP (stage 3), considering two phases (i.e., ICF-CP without additional information (phase 1) and ICF-CP with additional information (phase 2)) with the participation of two raters. The coding duration was used as the indicator for efficiency. The biggest increase in agreement occurred in the comparison between using or not using ICF-CP: stage 1, phase 1 (kappa = 0.46; 95% CI, [0.26–0.66]) to stage 1, phase 2 (kappa = 0.69; 95% CI, [0.53–0.85]). For the same set of records used in stage 1, the coding duration was significantly shorter using ICF-CP (means for both raters, 205 ± 35 min vs. 30 ± 5 min). Similarly, comparing stage 2 with stage 3, we observed that the coding duration was much shorter for both raters when using ICF-CP. The results show that ICF-CP could provide important support to the coding of clinical records, namely rehabilitation goals.

Keywords: International Classification of Functioning · Disability and Health · Cerebral palsy · Coding platform · Inter-rater and intra-rater agreement

1 Introduction

The International Classification of Functioning, Disability, and Health (ICF) [1], released by the World Health Organization (WHO), is a classification system for describing functioning and health states [2] and provides a comprehensive model for the field of rehabilitation [3], facilitating the planning of services [4], the definition of rehabilitation

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goals [5], and the measurement of outcomes [6]. The publication of ICF in 2001 created an era of changes in the rehabilitation delivery process, especially for chronic conditions by impelling the analysis of health information under a new paradigm [7].

Using a common language for describing health and disability allows comparisons between services or interventions even using different data sources including unstructured clinical information [8]. To use ICF in practice, different tools and instruments are being proposed by researchers, including the development of core sets, recording forms, and guidelines for mapping information [9].

The ICF contains 1424 categories organized according to an alphanumeric system. Each category begins with a letter that corresponds to its component domain: b (body functions), s (body structures), d (activities and participation), or e (environmental factors). The letter is followed by between one and five numeric digits. Categories are organized by levels as a nested system, so it is possible to telescope from broad to very detailed items depending upon the needs of the different application domains.

Mapping information guidelines were first published in 2002 [10] with a special focus on instruments for assessment. The 2005 update [11] extended the possibility of mapping health technology instruments as laboratory or imaging exams. Another update was introduced in 2016 [12] adding the need of identifying the purpose of the linkage, the type of document, and the response options when the linking document is an assessment instrument. In addition to the mapping of assessment instruments, it is possible to find other examples of clinical information linkage to ICF [13–15] and, irrespective of the different updates, the basis of the process was not substantially changed.

The usual mapping process involves at least two raters that should be well-familiarized with ICF's concepts and terminology. Independently, the raters should identify all the meaningful concepts in the information text, and the next step consists of matching each meaningful concept to the correspondent most specific category (the highest possible level) in ICF. Some information contained in the text, such as that relating to satisfaction with life or even some risky behaviors for health, is not possible to link [11, 16]. When mapping differences occur, a consensus must be reached between raters, which increases the time spent on the process. In addition to being a time-consuming process, the degree of agreement in the mapping varies depending on the knowledge and the previous experience of the raters, and by the type of information to be coded [13].

The motivation for implementing the ICF-Coding Platform (ICF-CP) was the need for tools to shorten the mapping process′s duration while raising its reliability by increasing the agreement between raters. Potential users of this tool include health professionals in clinical practice, researchers, and policymakers interested in comparing the description of functioning and health states.

Reliability and agreement are fundamental for any instrument since they describe the amount of error inherent to the measure [17], which is the basis for starting or continuing the validation process. In this work, we focused on inter-rater agreement, with different raters using the same procedure to link ICF to the same set of information, and on intra-rater agreement, where the same rater used the same procedure to link ICF to the same set of information at different times, both using and not using ICF-CP. An analysis of the efficiency using time required for coding as a criterion, was also performed as a secondary objective.

2 Materials and Methods

2.1 Coding Platform

The ICF-CP is a web platform supported by MongoDB, whose preliminary version is described in [18]. The platform is based on a client-server architecture (Fig. 1).

The client-side, responsible for the user interaction, provides HyperText Markup Language (HTML) pages to support the execution of the different actions. When data is required from server, the required parameters are expressed in JavaScript Object Notation (JSON) format and a RESTful Application Programming Interface (API) is used.

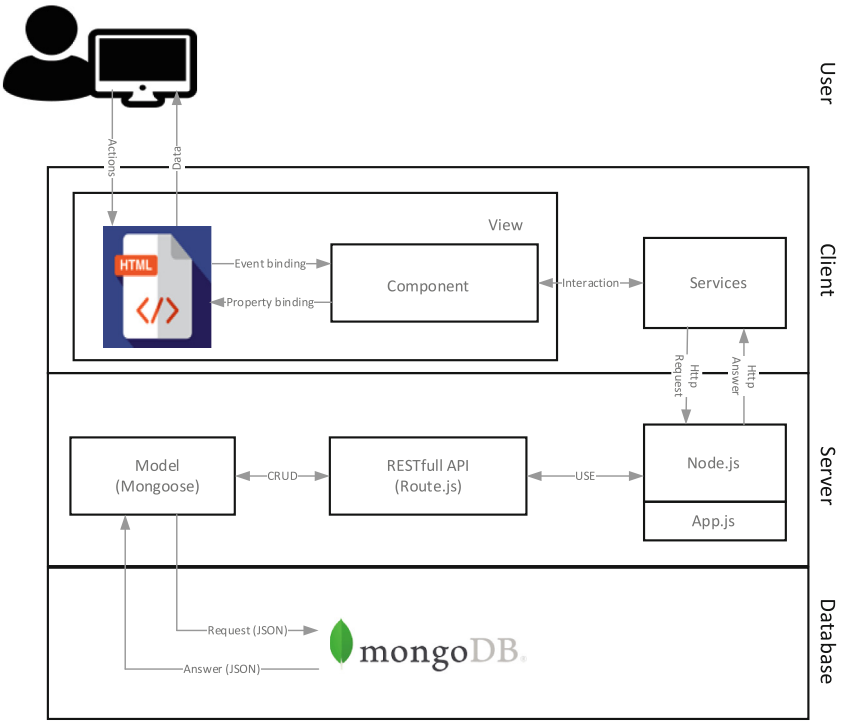

Fig. 1. Web platform architecture.

From the servers' point of view, each request is initially accessed by Node.js threading and then sent to the server using Express. The Create, Read, Update and Delete (CRUD) operations are performed on the MongoDB-supported database, with the help of Route.js to define the endpoints of the CRUD operations, and Mongoose library-defined data models, which are schemas that map collections of MongoDB and whose dependencies are expressed by a App.js file.

In the context of development disabilities, the following therapeutic objective might be used as a coding example: "to explore a toy with both hands for five minutes, without

bringing it to the mouth, under the guidance of a relative". ICF category d1310 (i.e., "learning through simple actions with a single object") can be used to code the action "to explore a toy with both hands". However, if the aim is also to consider the environmental factors, then ICF category e310 ("immediate family") must also be considered.

To optimize the ICF mapping, ICF-CP records all the codings made, namely those that have been consensual; based on that register, it can provide suggestions for each new item to be coded. As such, when there are previously coded items, an increase in the level of agreement between raters is predicted.

For example, if the goal is to code the expression "sit on the toilet", a rater may feel tempted to code this expression with ICF category d4103 (i.e., "sit - adopt a seated position with folded legs"). However, closer examination reveals that the expression is self-care (e.g., d5300, which may mean "regulating urination - adopting the appropriate position"). If this expression was previously coded, options other than ICF category d4103 could be suggested, thus reducing the probability of error.

ICF-CP aims to optimize the mapping of clinical interventions and their results [18]. Its interface allows the users to search for an ICF category introducing meaningful concepts with one or more words. The platform returns suggestions and statistics regarding the prevalence of ICF categories previously selected by other users based on the keywords searched. Moreover, registered users can add information to specific fields of inclusion and exclusion of each ICF category, which enriches the available suggestions.

2.2 Study Type and Information Source

This study is based on a secondary analysis of the existing records defining rehabilitation goals from a context therapy intervention [19] in children with cerebral palsy in Portugal. For each child, each week and together with the family, therapists defined one or two rehabilitation goals to be achieved and the corresponding strategies to be implemented. Rehabilitation goals were naturally written by therapists addressing the activity following the Specific, Measurable, Achievable, Relevant and Timebound (SMART) structure [20]. The coding of records that were used as a gold standard for comparison between raters was established in previous work and was developed following the guidelines mentioned above [10–12] and using additional instructions developed for the linkage of rehabilitation goals [13]. Moreover, we considered the guidelines suggested by Kottner et al. [21] for reporting reliability and agreement studies.

2.3 Rater Selection and Sample Size

The requirements for the raters were (i) having an academic degree in the health field, (ii) having previous knowledge and familiarity with ICF terminology, and (iii) having previous experience in linking health information to ICF. Due to the scarcity of resources to extend the procurement for raters that met the requirements, the work was carried out with two raters (i.e., the minimum number to accomplish the main objective).

For the estimation of sample size, we followed the work of Sim and Wright [22]: considering 50% as the proportion of positive ratings to detect a Cohen′s kappa of 0.90, for a two-tailed test null value of 0.40, with 80% power, and 5% statistical significance, 27 was the minimum number of meaningful concepts to be linked in each phase or stage.

As each record could contain one or two rehabilitation goals with two to five meaningful concepts, the number of records to be analyzed in each stage was set to ten. Records for analysis were randomly selected from a set of 2300 files.

2.4 ICF's Linkage Process Design

For data collection related to the linkage process, three stages were established using a different set of records in each, divided into two phases, which combined the mapping of rehabilitation goals with or without the support of ICF-CP (Fig. 2). The first phase took place over three weeks where the rehabilitation goals were coded without the support of ICF-CP in weeks 1 (n = 10) and 2 (n = 10) and with the support of ICF-CP in week 3 (n = 10). Before the second phase, additional information registered and suggested by raters during the first phase was validated and incorporated into the platform. The three-week interval between the two phases aimed to lessen the impact of memorization on linking the rehabilitation goals to the ICF. In the second phase, the linkage process was repeated with the support of ICF-CP on weeks 7 (n = 10) and 9 (n = 10) and without ICF-CP on week 8 (n = 10). The linkage process duration for each phase and stage was also registered. The raters conducted all the linkage processes individually and independently.

2.5 Data and Statistical Analysis

The raters' data were analyzed and are expressed in terms of inter- and intra-rater agreement using both absolute agreement and Cohen's kappa statistics with 95% confidence

		Stage 1	Stage 2	Stage 3
Phase 1	Week 1	Set 1 of records (n=10) coding with ICF-CP		
	Week 2		Set 2 of records (n=10) coding with ICF-CP	
	Week 3			Set 3 of records (n=10) coding with ICF-CP
	Weeks 4,5,6	Insertion of additional information and examples in the system		
Phase 2	Week 7	Set 1 of records (n=10) coding with ICF-CP		
	Week 8		Set 2 of records (n=10) coding with ICF-CP	
	Week 9			Set 3 of records (n=10) coding with ICF-CP

Fig. 2. Phases and stages of record coding.

interval (CI) calculation as indicators. The interpretation of Cohen's kappa is: (i) values of 0.01–0.20 indicate no agreement; (ii) 0.21–0.39, minimal agreement; (iii) 0.40–0.59, week agreement; (iv) 0.60–0.79, moderate agreement; (v) 0.80–0.90, strong agreement; and (vi) above 0.90, almost perfect agreement. For data analysis, we used IBM SPSS 24.0.

2.6 Ethical and Regulatory Considerations

All records were anonymized for coding purposes and the study was conducted according to the ethical principles originating from the Declaration of Helsinki and all the applicable laws and regulations (process number 10748/2015 and authorization number CNPD 11260/2015).

3 Results

3.1 Study Selection

The number of meaningful concepts varied between 29 for stage 2 and 41 for stage 3, whereas the number of ICF categories was the same (for stage 2) or slightly more (for stages 1 and 3), in this case indicating that a meaningful concept was mapped to more than a single category (Table 1). Despite some information being classified as "not covered", most of the ICF categories were linked to the activities and participation, or environmental factors ICF components.

Absolute agreement between raters for phase 1 was 0.65, 0.83, and 0.78 for stages 1 to 3, respectively; for phase 2, it was 0.80, 0.75, and 0.82, respectively (Table 2). Agreement among raters without using ICF-CP ranged between 0.46 (95% CI [0.26–0.66]) and 0.75 (95% CI [0.59–092]), with the lowest value being found in stage 1 of phase 1. When using ICF-CP, the agreement values ranged between 0.60 (95% CI [0.43–0.77]) and 0.69 (95% CI [0.53–0.85]). Although the highest values of agreement between raters were found in stage 2 (phase 1, kappa = 0.75; 95% CI [0.59–092]; phase 2, kappa = 0.72; 95% CI [0.55–0.90]) where the ICF-CP where not used, an increase, not statistically significant, in agreement occurred in stage 1 of phase 1 (kappa = 0.46; 95% CI [0.26–0.66]) to stage 1, phase 2 (kappa = 0.69; 95% CI [0.53–0.85]). In stage 3, where ICF-CP was used in both phases, the obtained agreement values were similar (phase 1, kappa = 0.60; 95% CI [0.43–0.77]; phase 2, kappa = 0.62; 95% CI [0.46–0.78]) (Table 2).

Intra-rater agreement for rater 1 varied between 0.58 (95% CI [0.38–0.79]) for stage 2 and 0.66 (95% CI [0.50–0.83]) for stage 1, whereas for rater 2, the lowest value was 0.49 (95% CI [0.29–0.68]) in stage 1 and the highest in stage 2 (kappa = 0.90; 95% CI [0.78–1.00]) (Table 2).

For the same set of records used in stage 1, the coding duration was significantly shorter using ICF-CP (means for both raters, 205 ± 35 min vs. 30 ± 5 min, $p < 0.001$). Similarly, comparing stage 2 with stage 3, we observed that the duration of the coding time was much shorter for both raters when using ICF-CP (Table 3).

Table 1. Goals, meaningful concepts, and ICF categories included in each stage.

	Stage 1	Stage 2	Stage 3
Goals, n	10	10	10
Meaningful Concepts, n	37	29	41
ICF Categories (total), n	40	29	45
Structures and Body Functions, n	1	-	-
Activities and Participation, n	22	13	22
Environmental Factors, n	9	7	11
Not covered (place, time, …), n	8	9	12

Table 2. Inter- and intra-rater results of rehabilitation goals records linked to ICF.

	Inter-rater agreement			Intra-rater agreement		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Phase 1						
Absolute	0.65	0.83	0.78	0,78	0,76	0,78
kappa	0.46	0.75	0.60	0.66	0.58	0.60
IC95%	0.26–0.66	0.59–0.92	0.43–0.77	0.50–0.83	0.38–0.79	0.43–077
Phase 2						
Absolute	0.80	0.75	0.82	0,65	0,93	0,80
kappa	0.69	0.72	0.62	0.49	0.90	0.62
IC95%	0.53–0.85	0.55–0.90	0.46–0.78	0.29–0.68	0.78–1.00	0.46–0.78

Table 3. Duration (in minutes) of the coding by stage and phase.

	Rater 1			Rater 2		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Phase 1 (duration)	240	180	30	170	160	35
Phase 2 (duration)	35	180	28	25	180	35

4 Discussion and Conclusion

This article presented a comprehensive study related to the analysis of the inter- and intra-rater agreement when mapping clinical information to the ICF using a coding platform. The results showed that the platform optimizes the time spent when coding

clinical records, namely rehabilitation goals, which means that it might be useful for those using the ICF framework both for clinical and research purposes.

The level of agreement between raters when the platform was used was similar, with their values being classified as moderate agreement. The stability of the results verified in stage 3 seems to guarantee homogeneity in the analysis of the records, despite the classification of moderate agreement. Stage 1 showed a slight increase, not statistically significant, in the agreement between raters when the platform was used, which improved from weak agreement to moderate agreement. This finding was confirmed by the results obtained in intra-rater analysis. In stage 1, the agreement of rater 1 could be classified as a moderate agreement; for rater 2, the value of kappa should be classified as a week agreement, showing variability between phase 1 and phase 2. On the contrary, in stage 3, both intra-rater agreement values could be classified as moderate agreement, showing the aforementioned stability of results.

The difficulty in reaching higher values of agreement could be explained by the diversity of the written rehabilitation goals. Not only the range of possible activities but also the fact that they were written in free language by different therapists made it necessary to introduce several coding examples and proposals to increase the coding accuracy.

Inconsistently, the highest kappa values were obtained when the mapping was performed without using the platform. This can be explained by the records being written objectively, directly addressing the ICF categories, without the need for any interpretation of the true intention of the author. Additionally, the proportion of references to categories not contained in the ICF, which do not require an option for a specific category, was higher in the records of stage 2. However, the total number of significant concepts and ICF categories was also lower in stage 2, which indicates that the objectivity of the rehabilitation goals contributed to the best results, which was verified in terms of the agreement. The intra-rater results of the two raters were quite different in stage 2: while one of the raters reached a value that could be classified as an almost perfect agreement, the other only reached a weak agreement, which also shows a considerable variability.

When considering the second aim of this work related to the efficacy of ICF-CP, the results showed a clear advantage obtained from its use. Using the platform reduced the coding time by about 75% of the initial time.

One of the limitations of this study was not controlling the queries used by each of the raters when using the coding platform, which could have led to divergences in coding. In future work, a comparison between using guidelines and free elaboration of queries could be useful to ascertain differences in agreement. Although not explored in this study, future studies could consider other functions of the ICF-CP such as adding information through examples, so that the increases in precision and accuracy of the mapping process could be measured.

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Optimization of Bucking Rules in the Forestry Industry Considering Taper Functions

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Abstract. The optimization of bucking rules during the forestry harvest is essential for increasing efficiency and profitability. Researchers have explored various taper functions to estimate tree diameters at different heights, which helps generate average tree profiles and assess trunk shape evolution. This study addresses optimizing bucking rules using taper functions to model log shape and maximize the yield from harvested trees. Here, we show that the exponential model is more efficient than the polynomial model regarding raw material utilization and computational time. Compared to previous beliefs, the exponential model does not reach the resolution time limit and demonstrates a steady increase in computational times as the number of logs increases. In contrast, the polynomial model frequently reaches the time limit and shows significant variations in computational times. These findings suggest that the exponential model offers a higher performance in forest resource utilization, which is crucial for the forestry industry's efficiency and cost reduction. Future research could focus on improving and adapting the polynomial model for specific problems, potentially leading to new insights and innovations in forest resource optimization.

Keywords: Exponential model · Polynomial model · Log cutting optimization · Cutting Stock Problem · Mathematical programming

1 Introduction

In the forestry industry, optimizing bucking rules during harvest is essential to increase efficiency and profitability [1]. Over time, researchers have explored various conceptualizations of taper functions for this purpose [2].

Taper functions have been used to estimate tree diameters, both internal and external (relative to the bark), at different heights or vice versa [3]. The concept of taper refers to the rate at which a tree narrows from its base to its tip [4], and these equations have been investigated for their predictive efficacy in species such as balsam fir [*Abies balsamea*],

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red spruce [*Picea rubens*], and white pine [*Pinus Strobus*] [5]. They have been used in various contexts, such as generating average tree profiles by age and assessing the evolution of trunk shape [6], or recovering the volume of sawn timber using sawing simulations [7].

For the wood industry, specifically bucking and sawing operations advances in automation and technologies provide opportunities to employ optimization techniques to improve efficiency [8]. While these decisions are essential to maximizing production volumes, costs must receive special attention [1] and the demand for lumber must be met with a limited supply of raw materials (log: tree length that is suitable for processing into lumber, veneer, or other wood products [9]) of various diameters and lengths [10].

In this regard, the bucking operation requires obtaining logs from the felled tree trunk to maximize its utilization to reduce costs by solving the Cutting Stock Problem (CSP) [11]. CSP is defined as cutting different pieces at specific locations to maximize benefits or minimize losses in the process. This application is widespread in the sawing process due to the importance of adequately utilizing logs [12]. CSP is classified by the dimensions of the object to be cut (one, two, or three dimensions) [13]. These problems are highly complex [14], because the CSP aims to complete an order with a specific number of pieces and dimensions at minimal cost, where the dimensions belong to an integer programming. The complexity of CSP is also noted in the work of [15], which is high due to its characteristics and variables. [16] classifies it as an NP-Hard problem and one that constantly evolves in its solution, contributing in his work a comparison of constructive and residual heuristics to solve cuts along the roll, minimizing material waste.

This study proposes and solves two mathematical programming models to optimize bucking rules in forest harvesting, using taper functions to model the trunk shape and maximize the number of products obtained.

The remainder of the article contains a literature review regarding taper functions, applications, and uses of optimization in this field in Sect. 2. In Sect. 3, we present the methodology applied in this work. The results are presented in Sect. 4. Finally, in Sect. 5, we present the conclusions of this work.

2 Literature Review

Researchers in the forestry field have conducted various studies on modeling using different functions and methods for multiple purposes, such as the use of digital terrestrial photogrammetry to estimate taper [17], modeling tree inclination using non-parametric methods, which, according to [18], have superior predictive quality compared to parametric methods, the development of a taper equation for white birch [19], and techniques to improve taper equations [20].

In the forestry industry, there are methods for generating bucking rules and planning for short-, medium-, and long-term operations. Among the first authors to address this topic were [21], who used Dantzig-Wolfe decomposition to determine the set of bucking rules that maximize revenue by generating columns to add new bucking rules with demand and supply constraints through dynamic programming.

[22] presented a mixed-integer linear programming (MILP) model that simultaneously considers decisions related to bucking activities (crosscutting) and distribution

(vehicle routing), which are generally considered separately and over different planning horizons. Additionally, [23], presented a mixed-integer linear programming (MILP) model that integrates bucking activities, raw material allocation, and transportation, aiming to improve efficiency and reduce costs in the forestry supply chain.

[24] optimized bucking rules using a dynamic programming approach at the trunk level, which involves maximizing the trunk value under certain market conditions. This approach allowed them to compare volume and value recovery between fixed-length and tree-length marketing systems. [25] used a U-Net architecture neural network model to define bucking rules for tree trunks, aiming to improve accuracy in wood volume calculation and species classification in forestry operations.

Specifically, for the CSP, [26] studied an overview of exact, heuristic, and meta-heuristic solution applications, such as those used by [27, 28] and [29], who addressed this problem, particularly the latter using column generation, a technique used to solve a combinatorial problem with several decision variables. Similarly, [30] proposed an integrated model for forest harvest planning and sawmill production with associated transportation and inventory costs. The complexity of this type of problem is highlighted by [16], as CSP can be applied to one-dimensional [31], two-dimensional [32], or three-dimensional [33].

3 Methodology

In this study, an analysis of stem profile functions for *Pinus radiata* was considered [34]. This evaluated and validated adjusted models for the mentioned species, testing nine different models. The data comes from 146 trees extracted from unmanaged stands located southeast of Buenos Aires province, Argentina (Sierras de Tandilia).

The samples had a breast height (DBH) diameter ranging from 6.7 to 45.2 cm and heights between 3.9 and 19.3 m. For model selection, the following indicators were used: Mean Squared Error (MSE), bias (E), standard deviation of residuals (SD), and graphical methods, among others (Table 1).

For the present study, the models proposed by Ormerod [36](Eq. 1) and Kozak [35] (Eq. 2) are considered. These will be presented below in the order above:

$$\left(\frac{d}{DAP}\right) = \left(\frac{H-h}{H-1.30}\right)^{0.80156} \tag{1}$$

$$\left(\frac{d}{DAP}\right)^2 = 1.26466 - 2.53619\left(\frac{h}{H}\right) + 1.31611\left(\frac{h}{H}\right)^2 \tag{2}$$

where:

$$DAP = Diameter\ at\ breast\ height\ ho$$

$$H = Total\ tree\ height$$

$$d = Log\ diameter$$

$$h = Log\ height$$

Table 1. Values of the model fit estimators

Model Used	MSE	E	SD	|E|
Kozak, 1969	0.0676	0.1885	0.2641	0.1844
Kozak et al., (1969)	0.0338	0.1147	0.2761	0.0770
Demaerschalk (1972)	0.0459	0.1241	0.2605	0.0944
Demaerschalk 1973	0.0287	0.1109	0.2848	0.0770
Ormerod (1973)	0.0266	0.0931	0.2561	0.0369
Newnham. 1990	0.0328	0.1361	0.2584	-0.0772
Goulding y Murray 1976	0.0649	0.1682	0.2361	0.1505
Goulding y Murray 1976. (2)	0.0881	0.1886	0.2711	0.1642
Thomas y Parresol. 1991	0.1240	0.2183	0.3027	0.1883

Source: *S*tem profile functions for Pinus Radiata *(adapted from* [34]*)*

3.1 Mathematical Model

The common equations for both functions are as follows:

Parameters

$t =$ *Amount of log type*

$d^1{}_t =$ Diameter at the top of log t

$d^2{}_t =$ Diameter at the bottom of log t

$h_t =$ Height of log t

$\varepsilon =$ Tolerance between the distance of logs t

Variabless

$$x_t = \begin{cases} 1 \ \textit{if} \ \log \ \ t \ \textit{is obtined} \\ 0 \ \textit{otherwise} \end{cases}$$

$$y_t = \textit{Distance between logt} - 1 \ \textit{and log t}$$

Objetive Function

$$MaxZ = \sum_{t=1}^{n} \left[\frac{1}{3}\pi \left(\frac{d_t^1}{2} \right)^2 h_t - \frac{1}{3}\pi \left(\frac{d_t^2}{2} \right)^2 h_t \right] x_t \tag{3}$$

Constrains

$$y_t \leq Mx_t \forall t = \overline{1, n} \tag{4}$$

$$\sum_{t=1}^{n} h_t x_t + \sum_{t=1}^{n} y_t \leq H \tag{5}$$

$$\alpha_t = \sum_{l=1}^{t-1} h_t x_t + \sum_{l=1}^{t} y_t \quad \forall t = \overline{1, n} \tag{6}$$

$$\beta_t = \sum_{l=1}^{t} h_t x_t + \sum_{l=1}^{t} y_t \quad \forall t = \overline{1,n} \tag{7}$$

$$x_t \in \{0,1\} \quad \forall t = \overline{1,n} \tag{8}$$

$$y_t \geq 0 \quad \forall t = \overline{1,n} \tag{9}$$

The Eq. (3) defines the objective function that seeks to maximize log volumes. Equation (4) considers that there is a distance between Logs if it is obtained. Equation (5) indicates that the total of obtained logs must be less than or equal to the total length of the tree. Equations (6) and (7) denote the lower and upper heights of the log, respectively. Equations (8) and (9) provide the nature of the variables.

For the use of the functions Ormerod (1973) [36] and Kozak et al. (1969) [35], the following constraints are added:

$$-M(1-x_t) + d_t^1(1-\varepsilon) \leq f(\alpha_t) \quad \forall t = \overline{1,n} \tag{10}$$

$$M(1-x_t) + d_t^1(1-\varepsilon) \geq f(\alpha_t) \quad \forall t = \overline{1,n} \tag{11}$$

$$-M(1-x_t) + d_t^2(1-\varepsilon) \leq f(\beta_t) \forall t = \overline{1,n} \tag{12}$$

$$M(1-x_t) + d_t^2(1-\varepsilon) \geq f(\beta_t) \quad \forall t = \overline{1,n} \tag{13}$$

$$-M(1-x_t) + \left(d_t^1(1-\varepsilon)\right)^2 \leq f(\alpha_t) \forall t = \overline{1,n} \tag{14}$$

$$\left(d_t^1(1+\varepsilon) + M(1-x_t)\right)^2 \geq f(\alpha_t) \quad \forall t = \overline{1,n} \tag{15}$$

$$-M(1-x_t) + \left(d_t^2(1-\varepsilon)\right)^2 \leq f(\beta_t) \quad \forall t = \overline{1,n} \tag{16}$$

$$\left(d_t^2(1+\varepsilon) + M(1-x_t)\right)^2 \geq f(\beta_t) \quad t = \overline{1,n} \tag{17}$$

Equations (10), (11), (12), and (13) ensure the correct obtaining of the logs for the Ormerod model [36] and (14), (15), (16), and (17) for Kozak [35]. It should be noted that the value of ε is the same for both functions, with a value of 5%. The value of M is estimated by 2DAP for Ormerod [36] and $4DAP^2$ for Kozak [35].

$$f(\alpha_t) = DAP\left(\frac{H-\alpha_t}{H-1.3}\right)^{0.80156} \tag{18}$$

$$f(\beta_t) = DAP\left(\frac{H-\beta_t}{H-1.3}\right)^{0.80156} \tag{19}$$

$$f(\alpha_t) = DAP^2\left[1.26466 - 2.53619\left(\frac{\alpha_t}{H}\right) + 1.31611\left(\frac{\alpha_t}{H}\right)^2\right] \tag{20}$$

$$f(\beta_t) = DAP^2\left[1.26466 - 2.53619\left(\frac{\beta_t}{H}\right) + 1.31611\left(\frac{\beta_t}{H}\right)^2\right] \tag{21}$$

The functions $f(\alpha_t)$ and $f(\beta_t)$, defined in Eqs. (18) and (19) for Ormerod [36] and (20) and (21) for Kozak [35], are transformed through a crucial tapering function. These functions refer to the estimated lower and upper diameters, respectively, considering a tolerance ε (Eqs. (15) and (19)).

In Fig. 1, the variables x_t and y_t, of the models, are represented. The T_j corresponds to the logs obtained by the cutting rules applied to the tree. The decision variables x_t in the image is those that obtain the value 1 associated with the logs obtained. The variables y_t correspond to the distance between log T_{j-1} and log T_j only in the case that log T_j is obtained.

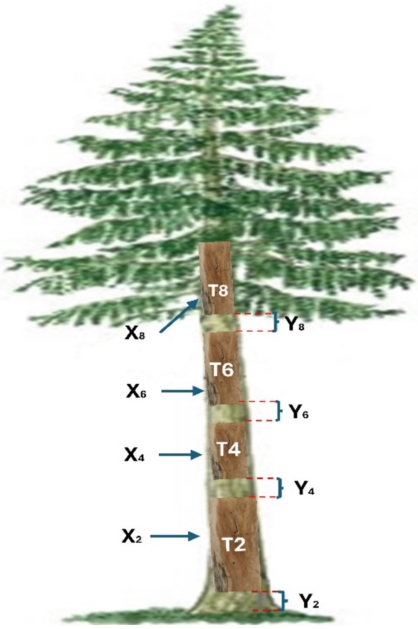

Fig. 1. Illustrated bucking rule on tree and decision variables of model.

The mathematical model presented in the previous chapter was computationally implemented in Julia with JuMP, using the SCIP 7.0.3 and GUROBI 9.5.0 solvers on a machine with the following technical specifications: OS Red Hat Enterprise Linux 9, CPU Intel (R) Core (TM) i5–3570 at 3.40 GHz, and 16 GB of RAM.

3.2 Instances

The instances used for the experiments belong to the work of [37], where the parameters are Total height value (H), Diameter at breast height value (DAP), and Log vector (h, d1, d2).

3.2.1 First Experiment

For the first experiment, we generated a series of test problems that varied in different parameters, encompassing a total of 11 trees with varying Diameter at breast height (DAP) and total height (H). To ensure a comprehensive dataset, we generated a set of 10 feasible logs for each tree. These logs were carefully estimated to include the log height (h), the upper diameter, and the lower diameter (d1 and d2, respectively), as dimensions for the study (Table 2).

Table 2. Log sizes used in the sawmill industry

Rough (m)	Slabs (m)	Latin American Market (m)
4.89	4.89	3.97
4.59	4.59	3.05
4.28	4.28	2.44
3.98	3.98	1.83
3.67	3.67	
3.37	3.37	
3.21	3.21	
3.06	3.06	
2.76	2.76	
2.45	2.45	

The exponential model was initially analyzed using the SCIP solver, employing the 11 instances mentioned earlier. Similarly, the polynomial model was used using the SCIP and GUROBI solvers.

3.2.2 Second Experiment

To better understand the behavior of both models, more complex instances were created to more clearly reflect the existing differences between both models regarding their solution quality and computation time. To achieve this, trees of heights 50, 55, 60, 65, 70, 75, and 100 m were considered. All trees had a DAP of 0.363 m, and a solution time limit of 600 s, equivalent to 10 min, was assigned to each solver.

4 Results

4.1 Objective Function Results, Times, and Number of Logs

For this analysis of the first experiment, tree heights ranging from 24 to 29 m and breast height diameters ranging from 0.342 to 0.39 m were used. The results obtained for the 11 instances described in the first experiment using the SCIP and GUROBI solvers are as follows (Table 3):

Table 3. Results of the exponential model using the SCIP solver

Exponential (Scip)	Objective Value (m^3)	Solver Time (s)	Number of Selected Logs
TREE 1	0.129	1.120	5
TREE 1.2	0.115	0.210	5
TREE 2	0.157	0.058	5
TREE 3	0.146	0.047	5
TREE 4	0.115	0.069	5
TREE 5	0.142	0.375	6
TREE 6	0.124	0.452	6
TREE 7	0.137	0.086	4
TREE 8	0.103	0.469	6
TREE 9	0.127	0.048	5
TREE 10	0.098	0.230	6

For the Exponential model solved by SCIP, the minimum objective value is obtained in TREE 10 with 0.098 and the maximum in TREE 2 with 0.157. Regarding solution times, the minimum is 0.047 in TREE 3, and the maximum is 1.120 in TREE 1. As for the logs, a minimum of 4 logs were obtained for TREE 7 and 6 logs for TREES 5, 6, 8, and 10 (Table 4).

For the polynomial model solved by GUROBI, the minimum objective value is 0.086 for TREE 8, with a minimum solution time of 0.274 for TREE 1.2 and 3 logs selected for TREE 1, 2, 5, and 7. The maximum objective value is 0.129 for TREE 5, with a maximum solution time of 6.675 for TREE 9 and 5 logs selected for TREE 10 (Table 5).

For the polynomial model solved by SCIP, the minimum objective value is 0.086 for TREE 8, with a minimum solution time of 1.546 for TREE 4 and 3 logs selected for TREES 1, 2, 5, and 7. The maximum objective value is 0.129 for TREE 5, with a maximum solution time of 7.749 for TREE 6 and 5 logs selected for TREE 10 (Table 6).

The exponential model solved by SCIP has an average objective value of 0.12, an average solution time of 0.28, and an average of 5.27 logs selected. In comparison, the polynomial model solved by GUROBI has an average objective value of 0.11, an average solution time of 1.19, and an average of 3.73 logs selected.

Table 4. Results of the polynomial model using the GUROBI solver

Polynomial (GUROBI)	Objective Value (m^3)	Solver Time (s)	Number of Selected Logs
TREE 1	0.094	0.946	3
TREE 1.2	0.097	0.274	4
TREE 2	0.124	0.613	3
TREE 3	0.119	0.686	4
TREE 4	0.111	0.547	4
TREE 5	0.129	0.533	3
TREE 6	0.098	0.968	4
TREE 7	0.128	0.617	3
TREE 8	0.086	0.308	4
TREE 9	0.113	6.675	4
TREE 10	0.088	1.011	5

Table 5. Results of the polynomial model using the SCIP solver

Polynomial (Scip)	Objective Value (m^3)	Solver Time (s)	Number of Selected Logs
TREE 1	0.094	1.741	3
TREE 1.2	0.097	2.341	4
TREE 2	0.124	1.962	3
TREE 3	0.119	1.917	4
TREE 4	0.111	1.546	4
TREE 5	0.129	3.268	3
TREE 6	0.098	7.749	4
TREE 7	0.128	2.749	3
TREE 8	0.086	2.628	4
TREE 9	0.113	1.662	4
TREE 10	0.088	5.025	5

When the same polynomial model is solved by SCIP, it yields the same average objective value of 0.11. However, the solution time increases to 2.96, and the average logs selected remain at 3.73. These results indicate that the exponential model, when solved by SCIP, offers a higher objective value and a shorter solution time compared to the polynomial model, regardless of the solver used. The fact that the exponential model selects more logs on average suggests a more efficient utilization of raw materials, which in turn, indicates a higher performance of forest resources.

Table 6. Averages of the objective, time, and number of logs per function and solver

	Objective Value (m^3)	Solver Time (s)	Number of Selected Logs
Exponential Average SCIP	0.12	0.28	5.27
Polynomial Average GUROBI	0.11	1.19	3.72
Polynomial Average SCIP	0.11	2.96	3.72

4.2 Computational Time Results

As previously emphasized, the time limit for model resolution, set at 600 s, plays a pivotal role in this study. It significantly influences the choice of resolution model for the log-cutting problem. The DAP (Diameter at Breast Height) for each instance was maintained at a constant 0.363 m.

The instances in this study were characterized by varying parameters, namely the tree height and the number of logs. This diversity was maintained by considering trees with heights ranging from 50 to 100 m and generating sets of logs with different combinations. The aim was to evaluate the behavior of the models concerning resolution time.

It is necessary to differentiate the results between each solver since each one directly influences the time associated with log selection, as some algorithms are more efficient for specific problems.

The first parameter analyzed from the results was the height of the trees. Bar graphs were created to present the resolution time for each height, considering the different quantities of logs studied.

The results obtained by the model and solver are as follows:

In Fig. 2, it can be observed that the variations in resolution time are not considerable concerning the increase in tree sizes. Between the heights of 65 and 70 (m), there is a decrease in resolution time for the quantity of 50 logs, suggesting that resolution time and height are not directly proportional. They are also not inversely proportional parameters because the resolution time increases for the same amount of logs at a height of 75 (m).

Figure 3 shows that the model utilized the resolution time limit from 65 m onwards. Variations are observed between heights of 50 and 60 m. Still, these represent only 40% of the sample, and it is impossible to infer if height is a relevant parameter for the polynomial model solved through the SCIP solver.

Figure 4 reveals a crucial aspect of the polynomial model's performance. Its computational times, when solved through the GUROBI solver, are notably faster than SCIP, but this advantage is only observed up to a height of 70 m. Beyond this point, the model's performance is significantly constrained by its time limit, a pressing issue that needs to be addressed in our analysis.

Another aspect to analyze is the resolution time concerning the number of logs for each model.

Figure 5 shows that the number of logs is a relevant factor when analyzing computational times for the exponential model, as there is a constant increase in computational

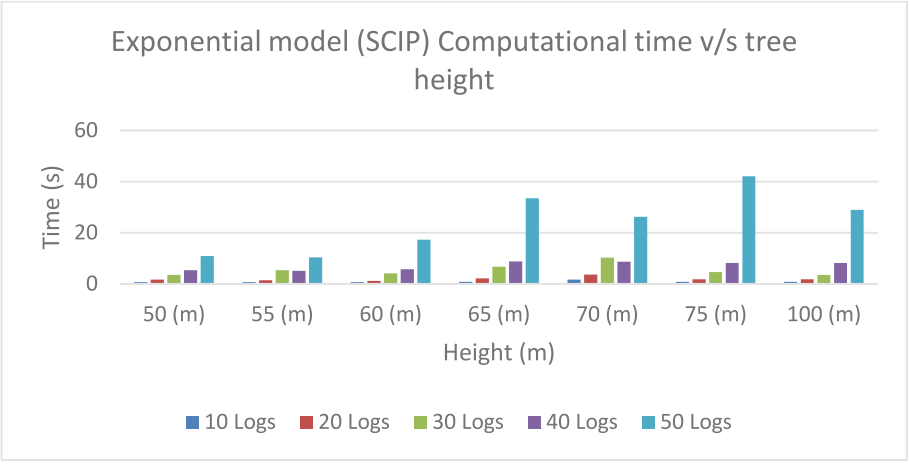

Fig. 2. Computational Time (s) vs. Tree Height (m) - Exponential Model (SCIP)

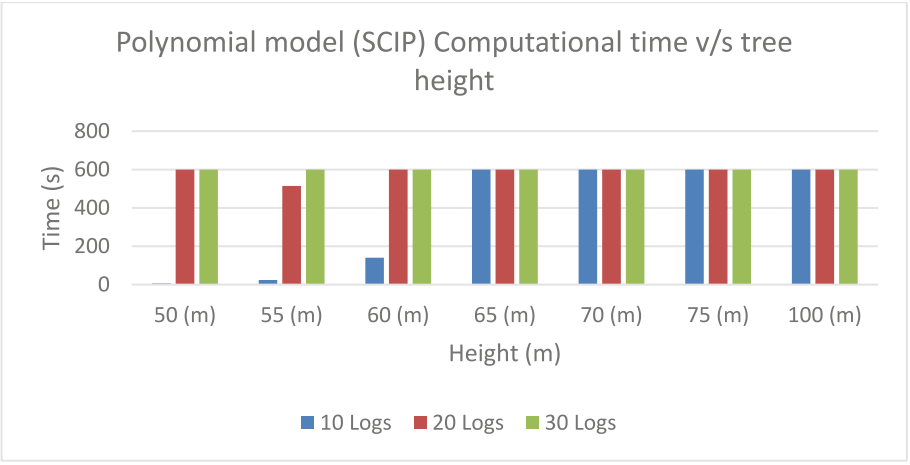

Fig. 3. Computational Time (s) vs. Tree Height (m) - Polynomial Model (SCIP)

time to find the optimum as the number of logs increases from different heights. The solver in this model resolved all instances, with the longest time being 42.06 s for 50 logs and a total height of 75 m.

Figure 6 shows that, for a total of 10 logs and a tree height of 65 m, the model already reaches the time limit and only resolves adequately in the instance of 20 logs at 55 m. In the other instances, the model only finds feasible solutions within 600 s of allocated computational time.

In Fig. 7, the computational times of the GUROBI solver remained constant for 10 logs. For the case of 20 logs, the model solved for heights from 50 to 65 m and used the total time from 70 to 100 m, finding only feasible solutions. For 30 logs, the model

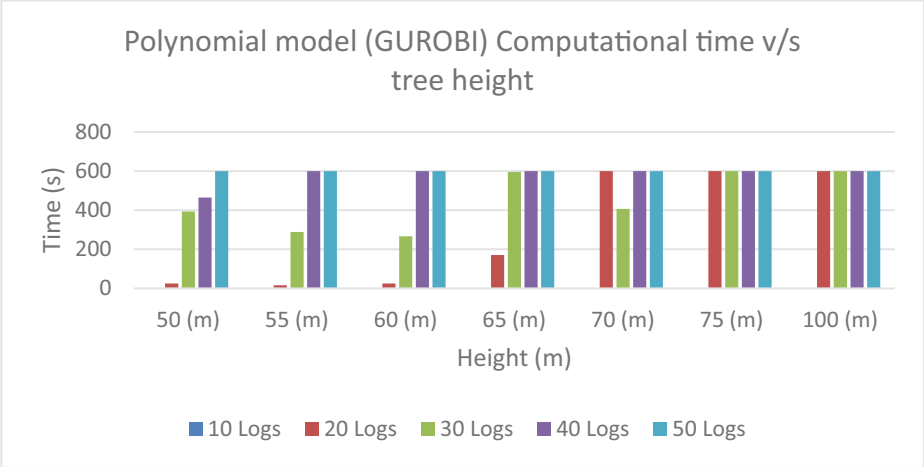

Fig. 4. Computational Time (s) vs. Tree Height (m) - Polynomial Model (GUROBI)

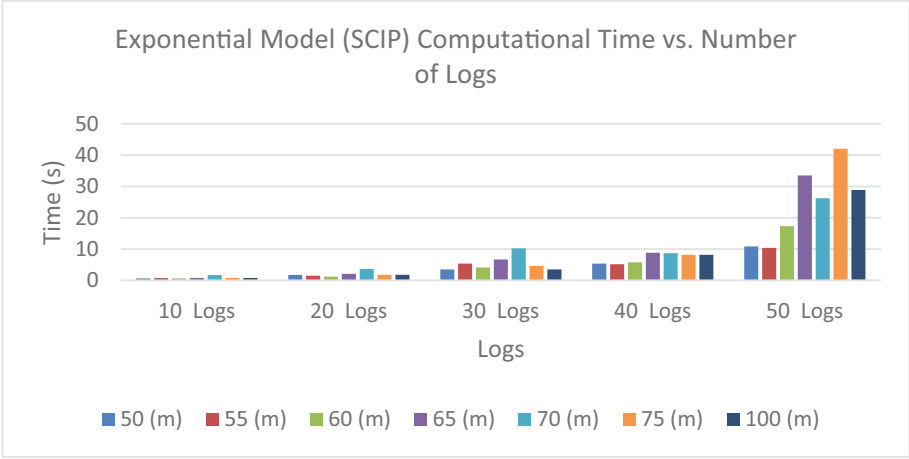

Fig. 5. Computational Time (s) vs. Number of Logs - Exponential Model (SCIP)

solved for heights of 50, 55, 60, and 70 m. For 40 logs, it only solved for 50 m, and for 50 logs, it used the maximum time at all heights.

It should be noted that the results obtained in these experiments are consistent with studies carried out by [38, 39] and [40], who point out that the exponential function generates better approximations for calculating the volume of the tree trunks, which supports our results.

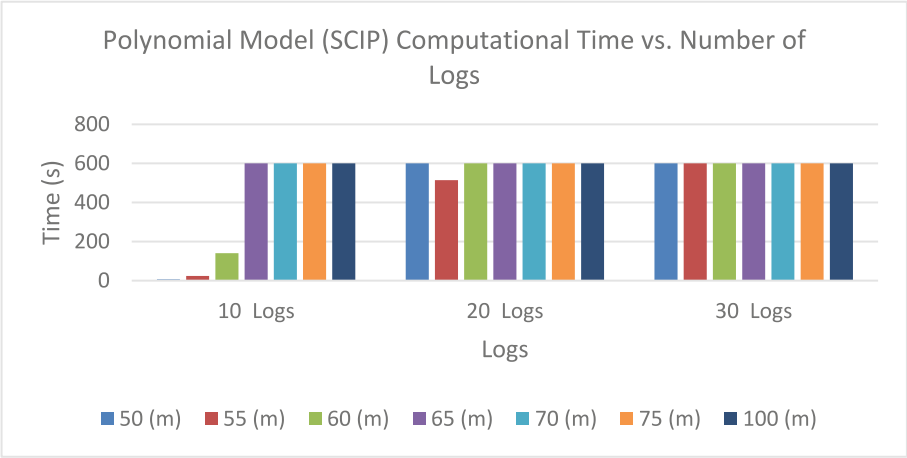

Fig. 6. Computational Time (s) vs. Number of Logs - Polynomial Model (SCIP)

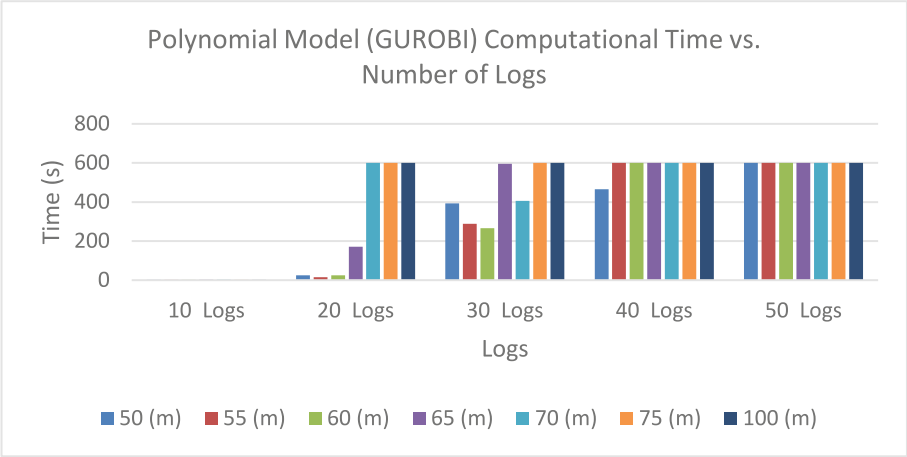

Fig. 7. Computational Time (s) vs. Number of Logs - Polynomial Model (GUROBI)

5 Conclusions

Based on the results, the exponential model shows greater efficiency than the polynomial model in raw material utilization and the required computational time. Unlike the polynomial model, the exponential model does not reach the computational time limit in any generated instance, while the polynomial model frequently does so even when analyzed with two solvers. This is crucial for obtaining optimal solutions, as computational times are high due to complexity. In this experiment, only feasible solutions were achieved within the assigned times.

The GUROBI solver computational time increases as the number of logs increases. For the polynomial model solved with the SCIP solver, it is impossible to deduce a relationship between the parameters of the number of logs and tree height with computational times, as this model reaches the time limit.

Our analysis underscores the crucial role of tree height and the number of logs as parameters affecting computational times. The exponential model demonstrates a steady increase in computational times as the number of logs increases, maintaining relative stability. In contrast, the polynomial model shows noticeable variations and frequently reaches the time limit in multiple instances.

The results obtained are consistent with previous findings in the literature and described in the results, where they found the exponential equation to be the most effective in describing log shape.

While the polynomial model did not yield as favorable results, future research could uncover improvements and adaptations for its application in specific problems, sparking new avenues for exploration and innovation.

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Ready for Digitization: Decision-Making Model for Low Code Development Platform Selection

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Abstract. In the ongoing digitalization process, low-code development platforms could be seen as promising solutions to help enterprises create their business applications in a short time . This is due to the use of different approaches such as visual modeling, model-driven development, rapid application development, and automatic code generation. On the market, there are plenty of vendors of low-code development platforms that propose a variety of products with similar parameters. In this regard, a mathematical model for evaluation and selection is proposed. This model considers three main groups of low-code development platforms assessment criteria. A characteristic feature of the model is that each group can be considered with a different degree of importance when forming the final decision. The applicability of the formulated decision-making model is demonstrated in a real example in the evaluation of five platforms according to 23 criteria distributed into 3 groups. The obtained results convincingly show the applicability of the proposed decision-making model in the assessment and evaluation of low-code development platforms.

Keywords: Low-Code Development Platforms · Decision-making · Model for Selection

1 Introduction

Computing solutions are a crucial aspect of information systems as they provide the technical infrastructure and tools for organizations to manage and process data [1]. Data intelligence is also a key area of information systems as it involves the collection, analysis, and interpretation of data to support decision-making and problem-solving. Sustainability is becoming an increasingly important aspect of information systems as organizations are recognizing the impact of technology. Therefore, a systematic approach to achieving appropriate standardization, leveraging process management methods and tools is needed [2]. Standardization of business processes is directly related to process

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performance and is a key driver for establishing successful business processes in an organization [3, 4]. Digitization aims to improve processes by using digital technologies and digitized data. Digitization therefore increases productivity and efficiency while reducing costs. However, digitization is a prerequisite for digital transformation, which is really a business transformation enabled by digitization. Integrating business processes, management tools and customer relationship management into one ecosystem allows the organization to build automated processes around them and consistently grow their business [5]. Digital transformation and the resulting innovations have fundamentally changed consumer expectations and behavior [6]. Some new models are identified as print-on-demand that address the problem of digital production in the book publishing industry [7]. In the context of digital transformation, process standardization is particularly important as it contributes to realizing the full value of digitization initiatives. Standardization considers the processes of implementing and developing inputs, work processes, and outputs that involve various stakeholders such as companies, consumers, interest groups, standards organizations, and governments. Standardization contributes to maximizing compatibility, interoperability, safety, repeatability, or quality [8]. The standardization also refers to cyber security as a major component of the efforts to enhance cyber resilience [9]. One of the possibilities for increasing the protection of information systems is cryptographic protection [10].

In this context, the standardization of business processes can be summarized as the implementation of unified business processes for the entire organization. Against this background, low code development platforms (LCDP) can be seen as a serious accelerator of digital transformation [11, 12]. Companies today are looking for cost-effective tools not only to improve their portfolio [13, 14] but also to help with the digitalization process while making their employees' lives easier. As a relatively new field, low-code software development platforms have some challenges that need to be considered [15]. On the other hand, successful project managers need the best solution, but plenty of available LCDPs all focused on the same features make this selection challenging. In this regard, the main question is how to choose the right low-code development platform. To answer this question, it is necessary to outline the main and most important features of LCDP related to managing and planning, scheduling, cost control, budget management, resource allocation, collaboration software, communication, decision-making, quality management, time management, and documentation or administration systems. In order to choose the most suitable LCDP, different criteria and functionalities should be considered to be integrated into a suitable mathematical model as shown in the current article.

The remainder of the article is organized as follows. The key features for evaluating LCDPs are discussed in Sect. 2. Problem formulation is presented in Sect. 3. The decision-making model for LCDP selection is described in Sect. 4. Experimental results are reported in Sect. 5. Section 6 contains a result analysis and discussion. Section 7 presents the conclusion and suggestions for future research.

2 Key Features for Evaluating Low-Code Development Platforms

The best low-code development platform depends on the individual needs of the company. Therefore, several basic questions need to be answered such as: What features does a workflow management tool need to have to manage projects successfully? Are the management tasks easy to use? Are there any unique features that set it apart from the competition? There are several key features when evaluating LCDPs to be considered as shown in Fig. 1.

Fig. 1. Key features for evaluation LCDPs

- **Project planning and scheduling or work breakdown structure (WBS).** This hierarchical structure allows breaking the project goal into actionable work stages that can be further divided into tasks or sub-tasks. This helps in planning every single aspect of the project. The WBS gives clarity about the needed time and resources and helps in setting the planned constraints for a project [16, 17]. The project schedule includes the ability to set due dates and milestones, as well as track the progress of tasks and dependencies. It can identify potential risks and problems that require corrective action at an early stage before they affect the project.
- **Gantt charts** are visual project roadmaps showing tasks, timelines, assignments, milestones, and dependencies. Gantt charts are one of the most important tools used in project management. They give a complete picture of the work breakdown structure

and help in the efficient allocation of resources (time, money, or people). These charts map the interdependencies of different work items and help in prioritizing critical tasks by checking for any deviations from the project plan and identifying delays.

- **Reporting and analytics** features help the project team adjust and reallocate resources when needed. This feature gives dashboards to uncover trends, form insights, and guide decisions.
- **Collaboration tools** refer to features supporting seamless communication among team members. For the project management software to be effective, it needs to have features that allow team members to communicate and collaborate effectively. This includes not only real-time communication but also document sharing (notes, comments, files) and collaboration on documents [18].
- **Version control and access control.** Using a version control system to manage complex projects has several benefits, from better collaboration to accelerated development. Version control software keeps track of every modification to the code in a special kind of database. Version control can track every individual change by each contributor and help prevent concurrent work from conflicting [19]. It should be noted that every version control system is different [20].
- **Integrations** make it possible to extend the functionality of LCDP by linking with other software, enabling a streamlined workflow. The best software tool must have the ability to integrate seamlessly with other tools and applications that are to be used and also the ability to import data from external sources.
- **Ease of use.** Ease of use of a tool directly affects team adoption and overall productivity. Ease of use is paramount, especially for those with no programming experience. A good tool is easy to use. Simpler steps and processes help users adapt easily without compromising the user experience [21].
- **Price** is one of the most important aspects of evaluation, and the total price includes a number of factors. The first is whether you want to deploy the software in the cloud or on-premises. In most cases, cloud pricing is based on the number of users per month using a subscription model. In the case of an on premise deployment, you typically pay a flat fee based on the number of users, and pricing is license-based. Vendors offer both monthly and annual plans, with the latter being cheaper.

What about security, scalability, and mobility? Enterprise LCAPs target a wider range of developers and provide features such as support for high performance, application availability and scalability, disaster recovery, security, API access to (and from) enterprise and third-party cloud services, usage monitoring, service level agreements and technical support availability, and training. In addition, it is worth to mention also that security needs to be the fundamental accent of the low-code development process and regular assessments, code reviews, and adherence to best practices are essential to mitigate risks.

In conclusion, it should be noted that low-code platforms are designed to be user-friendly, but there are still challenges requiring skills to handle complex problems and perform advanced customizations. Therefore, it is necessary to make sure that a skilled team is available to use the full potential of low-code development.

3 Problem Formulation

Among a predefined set of 5 LCDPs, it is necessary to select the most appropriate one to create a custom business application in response to the digital transformation. The features of these 5 LCDPs according to the data from Capterra [22] are shown in Table 1.

This entire set of LCDPs shown in Table 1 supports from 1 to 1000+ users, and this is the reason why this main criterion is not included in the selection since it is the same for the considered set of platforms.

Table 1. Features of LCDPs

#	Feature	Jira	Basecamp	monday.com	Salesforce	Trello
1	Approval Process Control	yes	--	yes	yes	--
2	Reporting/Analytics	yes	--	yes	yes	yes
3	Role-Based Permissions	--	yes	yes	--	--
4	Calendar Management	yes	yes	yes	--	yes
5	Compliance Tracking	yes	--	yes	--	--
6	No-Code	--	--	yes	yes	yes
7	Collaboration Tools	yes	yes	yes	yes	yes
8	Third-Party Integrations	yes	yes	yes	yes	yes
9	Graphical Workflow Editor	--	--	--	--	yes
10	Task Management	yes	yes	yes	yes	yes
11	Search/Filter	yes	yes	yes	--	yes
12	Task Progress Tracking	yes	yes	yes	yes	yes
13	Mobile Access	yes	yes	yes	--	yes
14	Document Management	yes	yes	yes	yes	--
15	Drag & Drop	yes	yes	yes	yes	yes
16	Real Time Data	--	yes	yes	--	yes
17	Workflow Configuration	yes	--	yes	yes	yes
18	Business Process Automation	yes	--	yes	yes	yes
19	Access Controls/Permissions	yes	yes	yes	yes	yes
20	Forms Management	yes	--	yes	--	--
21	Ease of Use	4.1	4.3	4.5	3.9	4.5
22	User Satisfaction	4.5	4.3	4.6	4.3	4.5
23	Pricing Model: Per User/Month, $	7.75	15	9	25	6

4 Decision-Making Model for Low Code Development Platform Selection

To make the selection of suitable LCDP several aspects need to be considered. These aspects can be interpreted as groups of evaluation criteria that refer to 1) the technical feature performance, 2) some subjective evaluation and satisfaction of a particular platform, and last is 3) the price. All these considerations can be expressed through the proposed mathematical model for evaluating LCDPs, formulated as follows:

$$LCDP^i = \max\left\{\alpha \sum_{p=1}^{P} e_{ip} + \beta \sum_{q=1}^{Q} e_{iq} - \gamma \sum_{s=1}^{S} e_{ih}\right\}, \forall i = 1, \ldots, N \tag{1}$$

$$\alpha + \beta + \gamma = 1 \tag{2}$$

where $i = \{1,2, \ldots, N\}$ represents the set of low-code development platforms to choose from, weighted coefficient α expresses the importance of technical feature performance, weighted coefficient β expresses the subjective evaluation and satisfaction such as ease of use, weighted coefficient γ expresses the relative importance about price or pricing model. The evaluations e_{ip}, e_{ih} and e_{iq} represent evaluation i-th LCDP about the corresponding group of criteria related to the performance of the technical features $p = \{1,2, \ldots, P\}$, evaluation about a group of criteria related to the price $q = \{1,2, \ldots, Q\}$ and evaluation about a group of criteria related to the subjective evaluations $s = \{1,2, \ldots, S\}$.

It should be noted that in the case of rapid decision-making, the group of evaluation criteria relating to the technical characteristics can be replaced by "yes" or "no", respectively by "1" or "0" about the presence or absence of the relevant characteristics. The relation (2) imposes normalization for the rest two evaluations concerning the subjective evaluation and price within a range between 0 and 1 to get a comparable scale. The relation (2) makes it possible to aggregate the separate three parts of evaluation regarding technical feature performance, subjective satisfaction, and price in the final generalized assessment. As can be seen from the ratio (1), the best choice is made by taking into account all three groups of criteria, which can be considered with different importance.

It is worth mentioning that the overall performance of a particular LCDP is based on the maximization of the groups of criteria related to features and consumer satisfaction and the minimization of the group of criteria related to price. This feature allows the model to be more flexible, taking into account different groups with different importance in determining the final performance.

The distribution of criteria into groups makes it possible to evaluate heterogeneous measurement units, and for this purpose, for each group of criteria, a corresponding normalization is used leading to values in the interval from 0 to 1.

The proposed mathematical model for the evaluation and selection of low-code development platforms (1) – (2) could be simplified by using a value equal to zero for the coefficient β ($\beta = 0$) and/or γ ($\gamma = 0$). In this case, the model (1) – (2) will rely on only the technical feature performance and subjective evaluation, or only the technical feature.

5 Numerical Testing

To verify the applicability of the proposed decision model (1) – (2) using the input data in Table 1, appropriate normalization needs to be performed. Following the proposed model, this normalization is simple and is shown in Table 2.

Table 2. Normalized parameters of LCDPs

No		Jira	Basecamp	monday.com	Salesforce	Trello
1	Approval Process Control	1	0	1	1	0
2	Reporting/Analytics	1	0	1	1	1
3	Role-Based Permissions	0	1	1	0	0
4	Calendar Management	1	1	1	0	1
5	Compliance Tracking	1	0	1	0	0
6	No-Code	0	0	1	1	1
7	Collaboration Tools	1	1	1	1	1
8	Third-Party Integrations	1	1	1	1	1
9	Graphical Workflow Editor	0	0	0	0	1
10	Task Management	1	1	1	1	1
11	Search/Filter	1	1	1	0	1
12	Task Progress Tracking	1	1	1	1	1
13	Mobile Access	1	1	1	0	1
14	Document Management	1	1	1	1	0
15	Drag & Drop	1	1	1	1	1
16	Real Time Data	0	1	1	0	1
17	Workflow Configuration	1	0	1	1	1
18	Business Process Automation	1	0	1	1	1
19	Access Controls/Permissions	1	1	1	1	1
20	Forms Management	1	0	1	0	0
21	Ease of Use	0.82	0.86	0.9	0.78	0.9
22	User Satisfaction	0.9	0.86	0.92	0.86	0.86
23	Pricing Model: Per User/Month, $	0.31	0.6	0.36	1	0.24

According to the proposed model (1) – (2), weighted coefficients related to the importance of performance of technical characteristics, subjective satisfaction such as ease of use, and importance regarding price are required to be determined. Two different cases expressing different degrees of importance for these three sets of criteria are examined, as shown in Table 3.

Table 3. Weighted coefficients about the importance of technical performance, subjective satisfaction and price

No	Feature/Criteria	Weighted coefficients	
		Case-1	Case-2
Technical performance		**0.8**	**0.4**
1	Approval Process Control	0.04	0.02
2	Reporting/Analytics	0.04	0.02
3	Role-Based Permissions	0.04	0.02
4	Calendar Management	0.04	0.02
5	Compliance Tracking	0.04	0.02
6	No-Code	0.04	0.02
7	Collaboration Tools	0.04	0.02
8	Third-Party Integrations	0.04	0.02
9	Graphical Workflow Editor	0.04	0.02
10	Task Management	0.04	0.02
11	Search/Filter	0.04	0.02
12	Task Progress Tracking	0.04	0.02
13	Mobile Access	0.04	0.02
14	Document Management	0.04	0.02
15	Drag & Drop	0.04	0.02
16	Real Time Data	0.04	0.02
17	Workflow Configuration	0.04	0.02
18	Business Process Automation	0.04	0.02
19	Access Controls/Permissions	0.04	0.02
20	Forms Management	0.04	0.02
Subjective evaluation and satisfaction		**0.1**	**0.3**
21	Ease of Use	0.05	0.15
22	User Satisfaction	0.05	0.15
Pricing Model		**0.1**	**0.3**
23	Per User/Month, $	0.10	0.30

These preferences are given by an expert authorized to make the selection of the platform by assigning the weights of the importance coefficients. Here should be pointed out, that the weighted coefficient for the importance of technical performance needs to be distributed among 20 technical features (Table 1 rows from 1 to 20). The weighted coefficient for the importance of subjective evaluation needs to be distributed among 2 features (Table 1 rows from 21 to 22) while the last coefficient contains only one feature referring to the price. The distribution of importance weights within each group of criteria can be the same for all sub-criteria or different depending on the expert's point of view.

Case-1 considers technical performance criteria as the most important with a value for this coefficient equal to 0.8 and the remaining two group of criteria with equal importance with a value of 0.1. Case-2 simulates the situation where technical criteria are also the most important with a value of 0.4 and the rest two also have equal importance with a value of 0.3.

Once the normalization is done and weighted coefficients are determined, it is possible to use the proposed model to evaluate the overall performance of each alternative or LCDP. The obtained results based on the information from Table 2 and Table 3 are analyzed in the next section.

6 Result Analysis and Discussion

The results of the simulated 2 cases for the relative importance between the groups of criteria in accordance with the expert's point of view are shown in Fig. 2.

In Case-1 where the technical performance criteria are the most important (weighted coefficient is equal to 0.8), the best-suited alternative is "monday.com". All technical sub-criteria along with subjective sub-criteria are considered with equal importance. Under an analogical scenario but with a value for the weighted coefficient about technical performance criteria equal to 0.4 and a weighted coefficient value of 0.3 for the other two groups, it also shows that the best selection should be "monday.com".

Let's see how the other platforms rank according to their overall performance. The comparison between these two rankings is visualized in Fig. 3.

In Case-1, where the technical characteristics of the LCDP are most important according to the expert, the ranking of the platforms is as follows: 1) "monday.com" with a value of 0.815; 2) "Jira" with a value of 0.695; 3) "Trello" (0.664); 4) "Basecamp" (0.506); and 5) "Salesforce" (0.462) as shown in Fig. 3.

Case-2 illustrates the situation where the expert's preferences are almost equal for all three groups of criteria with a very small preponderance of the technical parameters (0.4; 0.3; 0.3). The ranking under these circumstances is as follows: 1) "monday.com" (0.545); 2) "Trello" (0.492), 3) "Jira" (0.485); 4) "Basecamp" (0.318); and 5) "Salesforce" (0.186) (see Fig. 3).

It is observed that in both ranking lists only the second and third are interchanged – in Case-1 "Jira" is before "Trello" while in Case-2 "Trello" is before "Jira". In these ranking lists, sub-criteria within all groups are considered with equal importance and only weighted coefficients about the groups of criteria differ. The limitations of the formulated model are related to simplified assumptions about equal sub-criteria weights

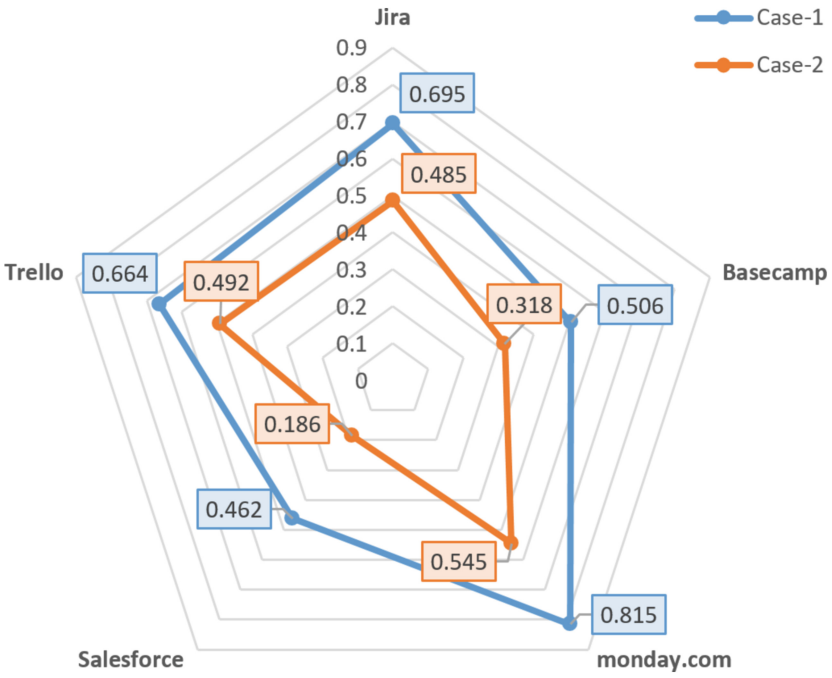

Fig. 2. Overall performance of LCDPs under different importance between groups of criteria

Fig. 3. Comparison between platforms rankings under Case-1 and Case-2

and one decision-maker. For further model enhancement is planned to modified the proposed model for a more precise evaluation of the features of LCDP involving more than one expert to express his preferences not only about the group of criteria but also about the importance between sub-criteria [23, 24]. In addition, proposed model could be implemented in a software tool to make the evaluation process more efficient and

transparent for practitioners by developing a web-based tool where the experts could express their preferences.

Regardless of whether the proposed model for platform selection will be used or similar, the important thing is that it provides a clear and objective view of the capabilities of each of the evaluated platforms. In addition, the model used have be able to handle different types of data, since the characteristics and evaluation criteria of LCDP are of different dimensions.

Using LCDP helps to handle various tasks, thereby contributing to the organization and ability to track all tasks, deadlines and resources. So using LCDP can improve automation tasks and streamline workflow by improving communication skills and providing a central place to store and share information, and so its choice is important.

7 Conclusion

Business digitization enables businesses to make better data-driven decisions. Therefore, the demand for customized digital solutions continues to grow, as does the need for applications that are quick to deploy and do not depend on experienced software developers. The digitalization process requires changing business models that adequately reflect the resulting processes. In response to this need for fast and timely change, low-code development platforms have emerged, offering promising solutions for building applications in a very short time. The low-code/no-code approach is a relatively new and constantly evolving domain. Considering the availability of various low-code development platform vendors, a decision-making model for evaluation and selection of such a platform is proposed.

The proposed model is easy to use and considers the evaluation criteria in 3 distinct groups with multiple criteria. A characteristic feature of the model is that each group can be considered with a different degree of importance in forming the final solution. In this way, it is possible to evaluate disparate units of measurement, for which purpose a corresponding normalization is used for each group of criteria, leading to values in the interval from 0 to 1. The applicability of the formulated decision-making model is demonstrated in a real example in the evaluation of five platforms according to 23 criteria, distributed in three groups. The obtained results convincingly demonstrate the applicability of the proposed decision-making model in the assessment and evaluation of low-code development platforms. Based on the positive results, the further enhancement of the proposed model is related to involving more experts to express their preferences about the group of criteria and the importance of sub-criteria.

As future research, tests with more experts are planned to determine more precisely the importance of each of the evaluation criteria and model modification to group final decision making.

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"Pre-diagnosis and Referral of Patients to a Specialist Medical Team Through Facial Biomarker Detection"

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Abstract. Diseases can show facial characteristics and deformities, which can serve as diagnostic markers for various conditions like endocrine and metabolic syndromes, genetic disorders, and facial neuromuscular diseases. While facial recognition technology has been around for over fifty years, its use in clinical medicine has surged in the past decade. AI-based facial recognition has shown superior performance in diagnosing diseases. The research aims to establish a framework and methodology for identifying optimal algorithms and techniques for early diagnosis of neurodegenerative diseases. Through a comprehensive review and modeling of existing algorithms in the literature. The proposed development focuses on the early detection of neurodegenerative diseases to facilitate timely treatment and disease management. The implementation of the machine learning algorithms which are derived of convolutional neural networks (CNN), histogram of gradients (HOG), OpenFace 2.0 and supporting vector machine (SVM) in the proof-of-concept simulation achieve an accuracy of 87,5% and an F1 Score 83,3%. These results and its approach show a superior risk detection accuracy than that of the human physicians and thus is a viable diagnostic support for identifying neurodegenerative illness and referring patients to the appropriate medical specialist.

Keywords: Machine Learning · Artificial Intelligence · Computer Medicine · Facial Landmarks · Neurodegenerative Diseases

1 Introduction

The timely and accurate diagnosis of neurodegenerative diseases remains a critical challenge in contemporary public healthcare [1]. Strained by increasing patient populations and limited resources, current healthcare systems often struggle to deliver efficient diagnostic pathways for these debilitating conditions [2]. Delays in diagnosis can have a negative impact on patient outcomes, hindering the initiation of crucial treatment interventions and compromising overall quality of life. In this context, there is a pressing need for innovative solutions to streamline the diagnostic process for neurodegenerative diseases.

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This paper explores the potential proof of concept that leverages advancements in facial recognition technology and machine learning algorithms to address this critical healthcare challenge. By analyzing facial features and patterns it aims to identify potential biomarkers associated with neurodegenerative diseases such as Alzheimer′s disease (AD), Parkinson′s disease (PD), and Amyotrophic Lateral Sclerosis (ALS)[3]. This novel approach holds significant promise for revolutionizing the diagnostic landscape of neurodegenerative diseases by facilitating:

- **Earlier Pre-diagnosis:** The potential to detect neurodegenerative diseases at earlier stages, even before the manifestation of prominent clinical symptoms. Early detection is crucial for timely intervention and disease management strategies, which can significantly improve patient outcomes.
- **Expedited Referral Pathways:** It can function as a preliminary screening tool, flagging individuals who may require further evaluation by neurologists or other specialists. This targeted approach can significantly reduce wait times for specialist consultations and optimize resource allocation within the healthcare system.
- **Reduced Burden on Healthcare Systems:** By potentially enabling earlier intervention and disease management, it can decrease the long-term healthcare costs associated with neurodegenerative diseases.

Artificial intelligence (AI) is demonstrating substantial promise in transforming healthcare delivery. AI-powered algorithms exhibit superior accuracy compared to human radiologists when analyzing medical images, such as magnetic resonance imaging (MRI) scans [4]. This has the potential to expedite diagnoses, exemplified by the identification of Alzheimer′s disease. Furthermore, AI can leverage vast datasets to personalize treatment plans, potentially reducing adverse effects and improving patient outcomes [5]. These advancements could help diminish expenditure in Chile where leading causes of death are circulatory diseases [6] and cancer [7], which accounts for 45% of the causes [8]. By facilitating earlier diagnoses and optimizing treatment strategies, AI can significantly reduce healthcare burdens and contribute to improved population health [9].

The methodology of the development considers the stages of creation and training of the machine learning algorithm and support infrastructure. We will also discuss the ethical considerations surrounding user data privacy and informed consent. Finally, the paper will explore the potential impact of the solution on revolutionizing the diagnosis of neurodegenerative diseases and ultimately, enhancing patient quality of life.

2 Methodology

The proposed solution to this problem and its development and evaluation relies on a combination of established methodologies to ensure a robust, secure, user-friendly software with the potential to revolutionize the diagnosis of neurodegenerative diseases (Fig. 1).

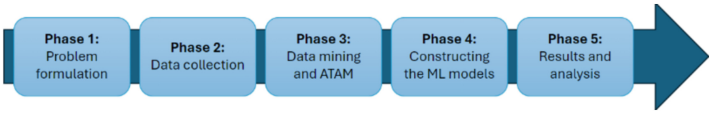

Fig. 1. Operational architecture diagram.

2.1 Building a Strong Foundation: Architecture Tradeoff Analysis Method (ATAM) for Architecture Development

The initial stages of development heavily emphasized the Architecture Tradeoff Analysis Methodology (ATAM) [10]. An ATAM workshop serves the critical purpose of introducing the entire team to the methodology, fostering clear communication, and establishing defined roles for successful application development. Additionally, the project vision was presented to potential associates from a research and development perspective, aligning their interests with the application′s potential impact on the healthcare landscape [11].

The chosen architecture, leveraging cloud-based services from Amazon Web Services (AWS) such as SageMaker, EC2, and Storage Buckets, was presented [12]. This cloud-based approach offered several advantages, including scalability, reliability, and cost-effectiveness, making it well-suited for the anticipated growth of the application [12].

The outcome of the ATAM workshop was the generation of a quality attribute utility tree. This utility tree outlined the critical quality attributes that would guide the development process. The team then analyzed the chosen architecture and application design. This rigorous analysis ensured that the application would not only be functional but also provide a secure and user-friendly experience for patients across diverse demographics [13].

2.2 KDD: Building the Brains of the App

The final key methodology employed in the development phase was the Knowledge Discovery in Databases (KDD) process [14]. This methodology provided a systematic framework for implementing the machine learning system, the core component responsible for analyzing facial features and identifying potential biomarkers for neurodegenerative diseases [15]. The KDD process involved several critical steps that ensured the accuracy and reliability of the machine learning algorithms.

The first step involved data selection. A licensed dataset from reputable sources, including BrainLat[16], and JPND Research Database [17], were chosen to train and develop the algorithm [18]. These datasets were specifically curated and organized for facial recognition applications, offering a robust foundation for the machine learning model [19].

Once the data was acquired, the KDD process transitioned to the preprocessing stage. Image and video data underwent a series of techniques to prepare them for analysis by machine learning algorithms. This included image cropping to focus on.

2.3 Simulation

The research will be tested in a simulated environment. For the research a mixed dataset containing already classified and doctored images of patients will be analyzed by algorithms and the output will be classified in risk vectors and analyzed [20].

The performance of the trained models will be evaluated using relevant metrics. The evaluation will be of each classification prediction and the risk probability classifier. Metrics will be based on the standard evaluation model using accuracy, precision, recall, and F1-score [21].

By incorporating these development stages and evaluation strategies, this research aims to establish a robust and effective framework for risk assessment and detection through facial biomarker.

2.4 Ethical Considerations

It is necessary to consider that during the project′s realization, legal barriers associated with the privacy and security of the information must be overcome. To this end, data anonymization measures are contemplated, generating tokens for the transmission of information. To this end, we will work together with cybersecurity experts to always guarantee data protection. In addition, an informed consent agreement will be generated for imaging to detect neurodegenerative problems.

3 Results and Discussions

In health, a quick and accurate diagnosis is essential to offer effective treatment and improve patient prognosis, and the proposal offers a promising solution in this regard.

There are multiple diseases or problems that can be detected with biomarkers on the skin and face [22]. These include:

- Endocrine, metabolic, and digestive tract diseases
- Genetic problems and chromosomal abnormalities
- Neuromuscular and psychiatric diseases
- Dermatological Problems
- Ophthalmological diseases

The development proposal is based on the early detection of neurodegenerative diseases as support in the timely treatment and arrest of these diseases [22].

By analyzing facial features, subtle changes in skin texture, and eye movement, you can identify potential signs of disease even before symptoms manifest. This approach already is changing the landscape in medicine as proven by the success of Face2Gene [23], a pediatric genetic disorder diagnostic software with a proprietary algorithm for early detection [24]. Early detection is crucial to extend survival and improve the quality of life of people who are affected. By identifying potential problems, workflows are streamlined, reducing the number of referrals needed to identify a general disease and improving patient prognosis.

The research's main objective is to determine a framework and development that allows the identification of the best algorithms and techniques to manage a pre-diagnosis

of neurodegenerative diseases. To this end, the existing algorithms in the literature are reviewed and modeled, taking accuracy and error as the main consideration [25].

3.1 Solution Architecture

The deployed software will follow the operation architecture guidelines of US National Library of Medicine National Institutes of Health [22] as shown in Fig. 2:

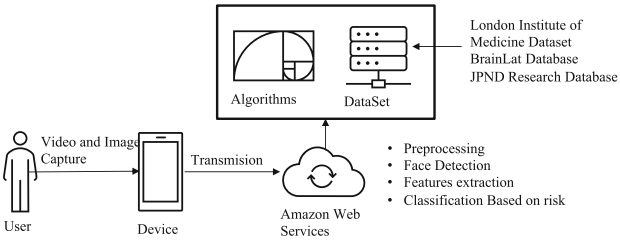

Fig. 2. Operational architecture diagram.

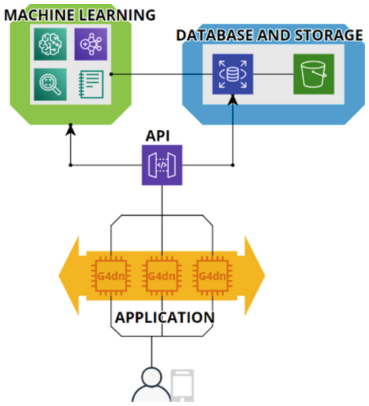

Fig. 3. AWS Cloud architecture of the proposed solution

Within Amazon Web Services seen in Fig. 3, the following architecture and components will be available:

- EC2: Amazon Elastic Compute Cloud (Amazon EC2) is a web service that provides secure, scalable compute capacity in the cloud [26]. These machines will be stored in an autoscaling group according to user demand as the solution requires [27].
- G4dn: Amazon EC2 G4 instances are the industry′s most cost-effective and versatile GPU instances for deploying machine learning models such as image classification, object detection, and speech recognition [28].
- Sagemaker: Amazon SageMaker is a fully managed service that brings together a broad set of tools to enable high-performance, low-cost machine learning (ML) for any use case [29].

- Sagemaker Notebook: It handles the code part and allows for parameter interaction within the established models for fine tuning [30].
- Rekognition: This module takes care of the various imaging data collected in this research and trains models based on the input data. It also takes care of deploying the models for prediction execution [31].
- AWS Elastic Map Reduce: This module oversees storing and deployment of the various models to use in the project [32].
- RDS: Relational Database System managed through the AWS console that can be automatically scaled when needed [33].
- S3: Storage Bucket that allows autoscaling when needed [34].

Once the system is deployed, it will grow elastically according to the demand for use. In this way, it will be possible to cover the largest number of people to open an option for early detection.

3.2 Architecture Tradeoff Analysis Method (ATAM)

By performing ATAM with the cloud architecture, the architectural scopes are identified, and the utility tree is generated.

Scenario Description
A hospital is looking to enhance its patient identification and monitoring processes by implementing new face detection software. The software needs to accurately detect and recognize patients' faces in various conditions, such as different lighting environments and varying angles. It should also be easy to integrate into the hospital′s existing systems and ensure patient privacy and data security.

Evaluation Tactics for Each Layer
Accuracy Layer Evaluation Tactics:

- Use standardized test images to measure detection accuracy
- Record the software′s performance metrics under different conditions.
- Conduct real-world testing with actual patients

Performance Layer Evaluation Tactics:

- Measure the time taken by the software to process a set number of images or video frames under different load conditions.
- Monitor CPU and memory usage during software operation.
- Scale up the workload gradually to test the software′s scalability and identify performance bottlenecks.

Robustness Layer Evaluation Tactics:

- Use controlled lighting setups to simulate different lighting conditions and evaluate the software′s performance.
- Introduce occlusions to test the software′s ability to handle obstructed faces.
- Capture images of patients at different angles and orientations.

Usability Layer Evaluation Tactics:

- Assess the software′s compatibility with the hospital′s existing systems and evaluate the ease of integration.
- Document the steps required to configure the software for different use cases or environments.
- Solicit feedback from hospital staff regarding the intuitiveness of the software′s user interface and the availability of documentation and support resources.

Security Layer Evaluation Tactics:

- Review the software′s privacy policy and data handling practices to ensure compliance with regulations.
- Conduct penetration testing to identify potential vulnerabilities.
- Evaluate the software′s data encryption and access control mechanisms.

Reliability Layer Evaluation Tactics:

- Monitor the software′s uptime and stability under normal operating conditions.
- Test the software′s error handling mechanisms.
- Assess the software′s ability to recover without data loss or disrupting patient care.

By applying these evaluation tactics to each layer of the utility tree, the study can thoroughly assess the face detection software′s suitability for their needs and make informed decisions about its implementation in their facility as shown in Fig. 4 the resulting quality attribute utility.

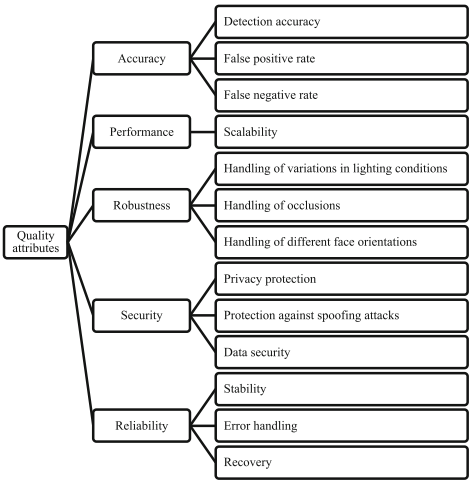

Fig. 4. Resulting quality attribute utility tree

3.3 Application of Knowledge Discovery in Database Methodology

To implement the Machine Learning system, the KDD methodology will be used. To do this, the following stages shown in Fig. 5 will be carried out, which are key parts of the recognized model for continuous knowledge acquisition and classification [35]:

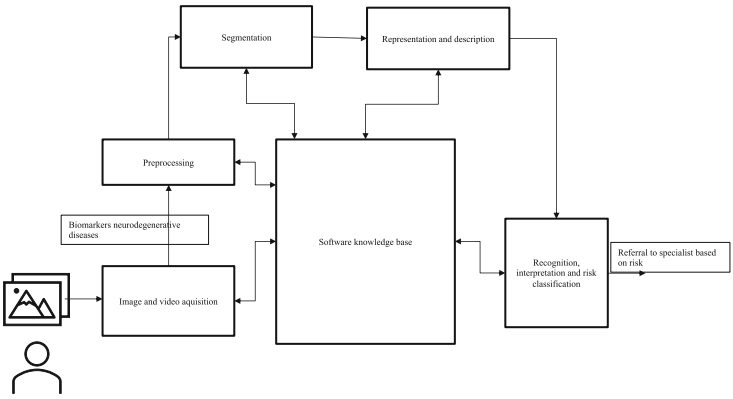

Fig. 5. Proposed data flow for knowledge acquisition

3.4 Data Selection

The images and videos to train the algorithms are obtained from BrainLat [16] and JPND Research Database [17]. These datasets are already organized and sorted by their classifiers. The chosen algorithm for each disease is developed and trained based on this data.

3.5 Preprocessing

To be able to work on the images and videos, the data is first pre-processed.

- Cropping the image: Centering the face and removing spaces that do not provide information.
- Scaling: Scales to a size of 244x244
- Normalization: The pixel values in the image will be converted to a common scale.
- Noise Removal: Masks Are Applied and CNNs Are Used
- Feature Enhancement: Histogram equalization method, brightness and contrast equalization.

3.6 Segmentation

There exists in the literature an abundance of algorithms and filters which suits different aspects of facial features pattern recognition for healthcare as show in Table 1. As such, Smoothing filters are applied to remove details that are not of interest. In addition, moving average filters will be made to increase sharpness and eliminate distortions. The filters chosen are:

- Histogram equalization
- Logarithmic transform
- Real and imaginary wavelet coefficient
- Denoise filter
- Moving median

Table 1. Facial Analysis Algorithms Available

Category	Algorithm
Appearance-based	Principal Component Analysis (PCA) Eigenface-Based Methods PCA Algorithm Kernel Principal Component Analysis (Kernel PCA) 2D-Image Principal Component Analysis (2D Image IPCA) Linear Discriminant Analysis (LDA) Discriminant Common Vectors (DCV) Independent Component Analysis (ICA) IPCA-ICA Supporting Vector Machine (SVM)
Feature-based	Geometric Features Local Binary Patterns (LBP) Elastic Bunch Graph Matching (EBGM) Histogram of Oriented Gradients (HoG) Elastic Bunch Graph (EBG) Hidden Markov Model (HMM)
Deep learning	Probabilistic-Decision-Based Neural Networks (PDBNN) Radial Basis Function (RBF) Convolutional Neural Network (CNN)

3.7 Representation and Description

At this stage, a gradient histogram is applied to obtain the most key features of the face. These features are then analyzed by these algorithms, which will segment according to the results. The algorithms available in the most promising studies were analyzed based on their accuracy as shown in Table 2. The following algorithms are chosen and used based on their success rate [36–39]:

- HOG
- OpenFace 2.0
- Random Forest
- Xception
- CNN with SGD
- Adam Optimizer

For testing the results, datasets are separated into 80% for training, 10% for testing, and 10% for validation. Once the data is ready the feature analysis is applied based on the biomarkers as shown in Fig. 6.

Table 2. Facial-recognition-based diagnosis systems for neurodegenerative diseases [22]

Study	Disease	Data	Sample Size	Method	Efficacy
Bandini et al. [39]	PD	Video	17 PD, 17 HC	Intraface tracking algorithm, Euclidean distance, SVM	Difference ($p <$ 0.05) between PD and HC
Rajnoha et al. [40]	PD	Image	50 PD, 50 HC	Random Forests, XGBoost	Accuracy = 67.33%
Jin et al. [36]	PD	Video	33 PD, 31 HC	Face ++, tremor extraction, LSTM neural network	Precision = 86%
Ali et al. [41]	PD	Video	61 PD, 543 HC	OpenFace 2.0, SVM	Accuracy = 95.6%
Hou et al. [42]	PD	Video	70 PD, 70 HC	HOG, LBP, SVM, k-NN, Random Forests	F1 = 88%
Nam et al. [37]	AD	Video	17 AD, 17 HC	OpenFace 2.0, extract movement coordinates to calculate Spearman's correlation coefficient	Difference ($p <$ 0.05) between AD and HC
Umeda et al. [43]	AD	Image	121 AD, 117 HC	Xception, SENet50, ResNet50, VGG16, and simple CNN with SGD and Adam optimizer	Xception with Adam showed the best accuracy = 94%
Bandini et al. [38]	ALS	Video	11 ALS, 11 HC	AAM, CLM, ERT, SDM, FAN	Accuracy = 88.9%

3.8 Recognition and Interpretation

Once the areas of risk for possible neurodegenerative diseases have been detected, segmented, and categorized according to the risk criteria, the user is given the information grouped by risk probability and will be referred to an appropriate specialist.

At the end of development, it is planned to reach a technological maturity level of TLR-7 [44]. According to the current methodology [45]. For the purposes of the study, a TLR-3 maturity level is reached.

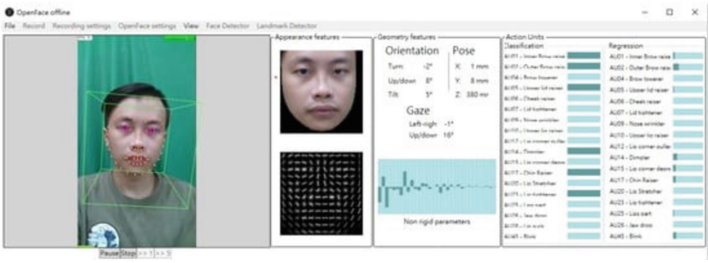

Fig. 6. The image registration process example of OpenFace.

3.9 Evaluation of the Proposed Methodology and Statistical Comparison

The evaluation metrics show an improvement on the machine learning detection algorithms in comparison with health professionals. This shows the viability of the methodological approach as F1 score which encompass the other metrics was 0,833 as shown in the Table 3 below:

Table 3. Evaluation metrics results of the machine learning algorithms

Accuracy	Precision	Recall	F1 Score
0,875	0,783	0,918	0,833

In contrast, specialists in neurodegenerative disease has a diagnostic accuracy of 79% notwithstanding the tests, referrals and time wasted before achieving the correct diagnostic as show in Table 4 [46]. This underlines the advantages of using the approach given as it is a robust tool which can assess with high accuracy, objectivity and gives a risk probability factor which permits a more in-depth analysis. Furthermore, the PoC would be a reliable tool in helping a diagnostician with substantial information on the first anamnesis of the patient.

Table 4. Diagnostic accuracy of doctors in detecting neurodegenerative diseases

Professional	Diagnostic accuracy
General Physician	0,733
Neurodegenerative Specialist	0,793

Within the results the confusion matrix shown on Fig. 7 obtained shows a 36% accuracy of true positive and 52% of true negative from the pool of cases.

It's important to note that the results of the algorithms are lower than that of the reference studies analyzed as the algorithm needs to generate a probability of risk for each disease, which in many cases have overlapping symptoms and facial biomarkers.

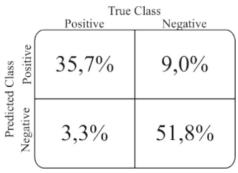

Fig. 7. Confusion matrix obtained from the result of the studies

The importance of early detection and the results as a tool for accurate diagnostics lies in the possibility of rapid treatment and palliative measures that can improve the conditions and prognostics of a patient.

4 Conclusions and Future Works

The facial recognition system has shown significant efficacy across a range of medical conditions, encompassing endocrine and metabolic diseases, genetic and chromosomal abnormalities, neuromuscular diseases, and acute and severe illnesses. Several software applications have been integrated into clinical practice. In comparison to conventional diagnostic methods, facial recognition-based detection offers heightened accuracy, objectivity, comprehensiveness, and information richness. Also, it can enhance the efficiency of healthcare systems.

On the other hand, reducing unnecessary diagnostic tests and streamlining workflows can lead to significant cost savings for health service providers and insurers. This can free up resources that can be used to improve patient care and invest in innovative technologies and treatments.

It is important to consider that the software is a tool for help with the detection of risks and not a diagnostic tool, so a professional is also needed for the treatment and final diagnosis. This study shows the viability of the approach and algorithms for a generation of risk probabilities which can help in the diagnostic process. Following the validations more healthcare areas can be added and measured in the process and the tool could be scaled to further encompass it.

4.1 Proposed Future Clinical Research and Application Methodologies

Once the software development stage is we can begin the product research stage to make improvements and complement the rest of the development. Future stages must consider the ease of use of such an application, especially on geriatric patients, so a thorough validation of the software is needed.

To validate the application, focus groups would be used, a control and a neurodegenerative disease patient. Two forms will be delivered: a SUS (System Usability Scale) form to measure the usability of the application and how recommendable this application is to other users and a TAM form that measures the user's attitude to use the application. This test can be repeated throughout development to ensure that the final application meets the quality criteria explored in the ATAM methodology described above.

To further analyze the clinical application, it's proposed to conduct a retrospective study supported by a cohort study to compare two focus groups and how the use of the software influences them. More specifically, the study aims to validate whether the use of the software improves the accuracy of diagnoses and relieves the burden on general practitioners and specialists. The results of this study could have important implications for the diagnosis and treatment of patients. If the software is shown to reduce the workload of generalists and specialists, it could help improve access to care and patient outcomes.

The study should be conducted by a multidisciplinary team with expertise in neurodegenerative diseases, medical diagnosis, and data analysis. The study should be designed to minimize bias and ensure the validity of the results. The retrospective study will be carried out in partnership with centers specialized in neurodegenerative diseases.

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Vertical Aeroponics as a Better Alternative for Sustainable Environment Control, a Simulation Approach

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Abstract. Climate change and soil erosion have impacted our potential for growing our own food. This, combined with the explosive urbanization of the capitals have pushed people to find new and innovative ways to grow their own food to give back to the planet and reduce their carbon footprint. One such way of achieving this is by growing a vertical aeroponic garden in their homes. This research proposes a methodology backed by multiple simulations on how to automate the process of growing crops through the help of multiple sensors and machine learning models which provide feedback and real time data to the user. This simulation compares a raised bed to a vertical garden, concluding a reduce of 76% of water usage, 90% land reduction and 95% reduction of carbon emissions with a yield of 10 lb of food.

Keywords: Machine Learning · Artificial Intelligence · Computer Medicine

1 Introduction

Urbanization and climate change have spurred the need for innovative and sustainable food production methods. Vertical gardens, utilizing aeroponics, offer a promising solution for cultivating crops in space-constrained environments [1]. However, achieving optimal growth conditions and maximizing yield within these systems requires precise control over environmental factors like nutrient delivery, light intensity, and temperature [2].

This paper explores the integration of Machine Learning (ML) techniques to vertical gardening systems. By leveraging sensor data collected from the growing environment, ML algorithms can learn complex relationships between plant growth and various environmental parameters. This knowledge can then be used to automate adjustments to nutrient solution composition, light exposure, and ventilation, ultimately fostering self-sustainable crop growth. This research depicts the efficacy of various ML methods, such as supervised learning and reinforcement learning, in optimizing vertical garden environments. Also, it further explores the types of sensors employed to collect the data necessary for robust ML implementation [3]. The insights gained from this research contribute to the development of intelligent vertical gardening systems capable of sustainable and high-yield crop production. To achieve this, several ML algorithms were

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compared utilizing the data gathered from the sensors to conclude which has the most accuracy and reliability as well as utilizing software to run simulations and validate the effectiveness of a vertical aeroponics system in reducing carbon emissions in a home setting.

2 National and International Context

There are several problems arising from rapid climate change and rapid urbanization, including:

1. Water stress and water scarcity
2. Food shortages and rising prices
3. Loss of green areas and spaces suitable for cultivation

Global water stress poses a critical challenge as population growth, industrialization, and climate change overwhelm water resources [4]. The increasing demand for water, coupled with inefficient use and pollution, leads to scarcity, endangering ecosystems and human well-being [5] (Fig. 1).

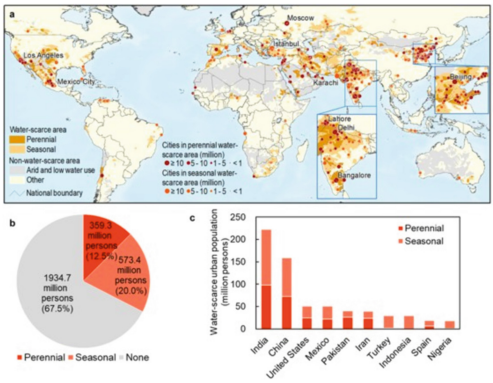

Fig. 1. a spatial pattern of large cities in water-scarce areas (cities with population above 10 million in 2016 were labeled). b Water-scarce urban population at the global scale. c Water- scarce urban population at the national scale (10 countries with the largest values were listed).

These shortages are intertwined with rising food prices, creating a situation where famine becomes an imminent threat [6]. As water scarcity disrupts agriculture, production of essential crops declines, amplifying food insecurity [7] (Fig. 2).

At the same time, global warming exacerbates these problems, contributing to extreme weather events, altering precipitation patterns, and rising temperatures. These changes further disrupt agricultural systems, intensify water stress, and increase the risk of food shortages [8].

The development proposes the adoption of an automated and optimized system that helps the public contribute passively and without violently disrupting their lifestyle that combines multiple solutions in a comprehensive system that packages the problem, is easy to install and negligible maintains [9].

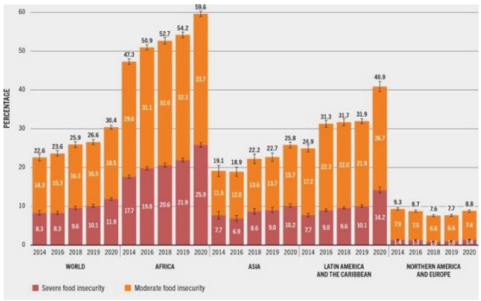

Fig. 2. Moderate or severe food insecurity remained unchanged at the global level from 2021 to 2022, with worsening food insecurity levels in Africa and in northern America and Europe, and improvements in Asia and in Latin America and the Caribbean

2.1 Harvestable Crops

For the development, vegetables, fruits, and herbs that can be grown were considered. For practical purposes and due to their nutritional density and rapid growth, it is decided to concentrate only on vegetables. [10] (Table 1, 2).

Table 1. Vegetables suited for aeroponic, growing season, harvesting and placement.

Plant	Growing Season	Harvest Method	First Harvest	Final Harvest	Best Airgarden Placement
Asian greens	Year Round (in mild climates)	Full Harvest	3 weeks	6 weeks	Top level
Broccoli	Autumn, Winter, Early Spring	Cut and Come Again	7 weeks	11 weeks	Bottom level
Brussels	Winter, Early Spring	Cut and Come Again	6 weeks	10 weeks	Bottom level
Cabbage	Autumn, Winter, Spring	Full Harvest	8 weeks	11 weeks	Bottom level
Capsicum	Late Spring, Summer	Cut & come again	7 weeks	10 weeks	Bottom level
Cauliflower	Spring, Autumn	Full Harvest	9 weeks	13 weeks	Bottom level
Celery	Autumn, Winter, Spring	Full Harvest	7 weeks	13 weeks	Any level

(*continued*)

Table 1. (*continued*)

Plant	Growing Season	Harvest Method	First Harvest	Final Harvest	Best Airgarden Placement
Chilli	Summer	Cut and Come Again	8 weeks	13 weeks	Middle level
Cucumber	Spring, Summer	Cut and Come Again	7 weeks	10 weeks	Bottom level
Eggplant	Spring, Summer	Cut and Come Again	8 weeks	10 weeks	Bottom level
Green beans	Spring, Summer, Autumn	Cut and Come Again	6 weeks	9 weeks	Bottom level
Kale	Year Round	Cut and Come Again	4 weeks	6 weeks	Any level
Leek	Year Round	Cut and Come Again	4 weeks	7 weeks	Bottom level
Lettuce	Year Round	Cut and Come Again	3 weeks	8 weeks	Any level
Peas	Autumn, Winter, Early Spring	Cut and Come Again	6 weeks	10 weeks	Bottom level
Radicchio	Late Autumn, Winter, Early Spring	Full Harvest	6 weeks	10 weeks	Any level
Silverbeet	Year Round (in mild climates)	Cut and Come Again	4 weeks	6 weeks	Top level
Spinach	Year Round (in mild climates)	Cut and Come Again	4 weeks	6 weeks	Any level
Sorrel	Spring, Autumn	Cut and Come Again	4 weeks	6 weeks	Any level
Squash	Spring, Summer	Cut and Come Again	6 weeks	8 weeks	Bottom level
Tomato	Spring, Summer	Cut and Come Again	7 weeks	10 weeks	Bottom level
Watercress	Spring, Autumn	Cut and Come Again	3 weeks	8 weeks	Any level
Zucchini	Spring, Summer, Autumn	Cut and Come Again	6 weeks	10 weeks	Bottom level

From the available options, those with the shortest germination time and the least user involvement are selected. In addition, its taken into account the positioning within the aeroponic tower, trying to maximize variety and access to light. On the other hand, vegetables that can be harvested multiple times and throughout the year are favored [11].

Table 2. Selected crops for the simulation

Plant	Growing Season	Harvest Method	First Harvest	Final Harvest	Best Airgarden Placement
Broccoli	Autumn,Winter,Early Spring	Cut and Come Again	7 weeks	11 weeks	Bottom level
Lettuce	Year Round (in milder cli- mates)	Cut and Come Again	3 weeks	8 weeks	Any level
Spinach	Year Round (in mild cli- mates)	Cut and Come Again	4 weeks	6 weeks	Any level

3 Design of the Solution

To assure the efficacy of machine learning in optimizing vertical garden environments, a controlled experimental setup was established utilizing an aeroponic vertical gardening system. This system cultivated diverse crops and employed a network of sensors to monitor critical environmental parameters. The following sections detail the specific setup, data collection procedures, and the machine learning methodologies implemented to achieve optimal plant growth conditions and maximize yield.

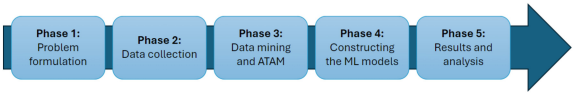

Fig. 3. Methodology phases to development SC simulation model.

Figure 3 describes the steps taken throughout this research to tackle the problem at hand. During phase 1 the problem was investigated and refined with brainstorming in order to propose a solution which would be validated with data gathered during phase 2. On phase 3 a data mining analysis takes place in order to describe the most critical data points that will aid the research and give way to constructing the ML models which would later be used in phase 5 to describe the results.

3.1 Hardware and Architecture

During the experiment, an Aeon Multisensor 6 monitored humidity, temperature, and light levels surrounding the crops [12]. Additionally, a sensor specific to aeroponics, such as a nutrient solution level sensor, will be employed. A camera is also included in the setup to capture high-resolution images for computer vision analysis. The data recorded by the sensors will be transmitted to a Raspberry Pi for initial processing before being sent to various Amazon Web Services applications for further analysis by the machine learning algorithms being served in the cloud (Fig. 4).

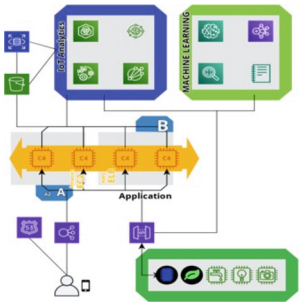

Fig. 4. Proposed Amazon Web Services Cloud IoT architecture

Figure 2 describes, from bottom to top, three layers composing the system. First is the user and the aeroponic tower which includes the multisensor, a light emitter and the water pump and automatic controls and a digital camera, all connected to a raspberry pi that is in constant communication through an API which sends the data to a webserver that handles all data and frontend of the application the user uses to know the state of their vertical garden. [13] The Application layer handles all incoming and outgoing data to control the vertical garden and ensure the IoT analytics and Machine Learning modules are in constant feedback for improving the model precision.

The IoT Analytics consists of 4 services:

- AWS IoT Device Management: It handles all the monitoring and automation management required by the vertical gardening system. [14]
- AWS IoT Greengrass Machine Learning: this service allows Machine Learning to run on connected devices reducing latency. [15]
- AWS IoT Things Graph: it serves important and relevant visual data to the user's frontend to see. [16]
- AWS IoT Analytics: it analyzes the data acquired by the sensors in the vertical garden. [17]

This data is shared then with the Machine Learning module consisting of 4 other services:

- AWS Sagemaker: it facilitates the machine learning process by building, training and deploying ML models for their use. [18]

- AWS Rekognition: it allows the use of computer vision through the data collected by the digital camera. [19]
- AWS Elastic MapReduce: this service is a managed Hadoop framework for processing and analyzing large datasets allowing its users to do Data Warehousing and Scientific Computing. [20]
- AWS Sagemaker Notebook: These notebooks store the code needed to fine tune the Machine Learning models to be deployed in this project. [21]

Leveraging advancements in computer vision and machine learning, intelligent monitoring systems can be developed for vertical gardens, fostering optimal growth conditions and maximizing yield [22]. Sensors monitoring temperature, humidity, and nutrient solution levels replacing the soil moisture sensor" for aeroponic systems can provide real-time data for machine learning models [23]. These models can then predict potential yields and suggest adjustments to environmental factors (light, irrigation, nutrient delivery) to optimize plant growth within the vertical garden.

A sensor designed for aeroponics is employed, such as a nutrient solution level sensor. This sensor provides real-time data on the availability of nutrients within the mist, ensuring that the plants receive the optimal balance for healthy growth.

A high-resolution camera integrated into the setup captures images for computer vision analysis tracking plant growth patterns by reviewing sequential images captured at regular intervals, features like leaf area and stem thickness can be extracted.

Data gathered by the sensors is transmitted to a Raspberry Pi for initial processing. The Raspberry Pi acts as a central hub, collecting and filtering the sensor data before sending it to various Amazon Web Services (AWS) applications.

While the Raspberry Pi prepares sensor data for further analysis, the real power lies in using this data for actionable insights. Machine learning algorithms, particularly deep learning models, excel at extracting knowledge from processed sensor data. These models can effectively classify various plant features based on image analysis [24].

These ML models can be trained on historical data to predict plant water requirements based on factors like real-time sensor data, historical water usage patterns, and plant growth stage allowing for targeted irrigation, minimizing water waste, and optimizing plant growth. [25, 26].

The models selected are based of Support Vector Machines (SVM), Random Forests (RF), Convolutional Neural Network (CNN) and Decision Trees (DT) for predicting plant health and irrigation requirements within an aeroponic vertical garden system. These supervised learning algorithms offer distinct advantages for this specific application.

By employing a combination of these algorithms, the research can leverage the strengths of each approach. SVMs can provide high accuracy in plant health classification, Random Forests can capture complex relationships and identify key influencing factors, and Decision Trees offer interpretability for informed irrigation decisions.

The steps taken for data mining and building these models are as follows:

3.2 Data Pre-processing

The sensor data collected from the aeroponic system will undergo a series of preprocessing steps to ensure its suitability for machine learning model training. This

includes handling missing data points, normalization, and potential outlier removal. Missing data points, if encountered, will be addressed using imputation techniques [27]. Normalization techniques will be applied to ensure all sensor readings fall within a specific range, facilitating model convergence during training [28]. Outlier detection and removal will be employed if statistically significant outliers are identified using techniques like interquartile range (IQR) [29].

For the computer vision aspect of plant health monitoring, the image data from the camera will also undergo pre-processing [30]. The specific pre-processing steps chosen for image data will be further elaborated upon after data acquisition is complete.

3.3 Feature Engineering

Following data pre-processing, feature engineering techniques might be applied to extract informative features from the sensor readings [31].

For image data, feature engineering techniques specific to computer vision tasks are employed: color histograms, texture features, or applying dimensionality reduction techniques like Principal Component Analysis (PCA) [32]. The specific feature engineering methods chosen for the image data will be determined based on the characteristics of the acquired images and the performance of the initial models.

3.4 Model Training

The pre-processed and potentially feature-engineered data will be used to train the chosen machine learning models. Hyperparameter tuning will be conducted using a grid search or random search approach to identify the optimal configuration for each model [33].

For growth detection using a large plant dataset a Convolutional Neural Network (CNN), will be trained. The chosen optimizer and learning rate scheduling strategy will be determined based on experimentation and best practices for CNN training [21].

3.5 Evaluation Metrics

The performance of the trained models will be evaluated using relevant metrics. For yield prediction, the mean squared error (MSE) will be employed to assess the model's ability to accurately predict crop yield [34]. For irrigation optimization, metrics like irrigation efficiency (ratio of beneficial water used by plants to the total water applied) will be considered [35].

3.6 Minimal Viable Product and Simulation

The proposed solution unit is described by the scheme in Fig. 5.

The minimum viable product is described in Fig. 5. For this, the final design of the aeroponic system and its various sensors must be built in order for customers to acquire. Sensors include the ones described in previous sections as well as an LED emitter and a water pump, irrigator and fertilizer mix system. All of this will be connected to the cloud architecture described in Fig. 3 in order to be fully automated .

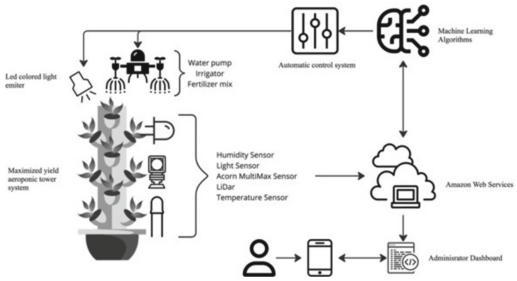

Fig. 5. Operational high level solution architecture

3.7 Architecture Tradeoff Analysis Method

Scenario

- The automated system works reliably and has an adequate response time.
- The kit is expected to respond quickly to changes in soil moisture and environmental conditions.
- Operations cares about system availability

Tactics Evaluated

Using Redundancy in Sensors and Actuators

- Ensure system availability
- Incorporate redundant sensors and actuators

Local Cache Implementation

- Improve response time
- Temporarily store relevant data
- Reduce dependency on a network connection

Code optimization to reduce response times

- Perform code analysis and optimization
- Reduce automated system response times

Scenario Analysis Results

- Implementing redundancy in sensors and actuators will increase system availability and provide greater reliability in the event of failures.
- Implementing a local cache in the mobile app will improve the user experience by reducing response times and allowing for more efficient use under conditions of limited connectivity.
- Optimizing the code will allow for more efficient operation of the automated system and mobile app, improving both availability and response times.

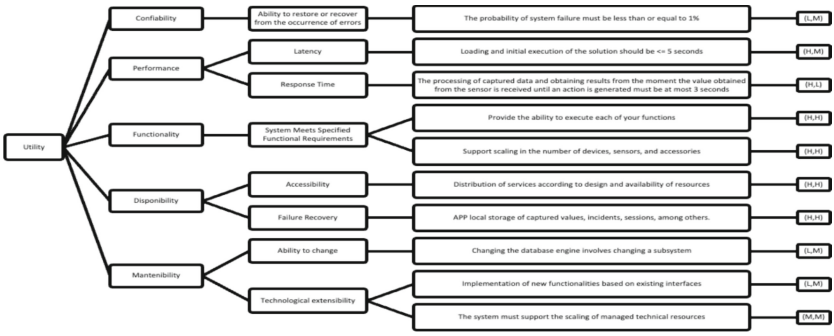

Fig. 6. Resulting quality attribute utility tree

3.8 Application of Knowledge Discovery in Database Methodology KDD

To implement the Machine Learning system, the KDD methodology will be used. To do this, the following steps will be carried out, which are key parts of the model (Fig. 6, 7).

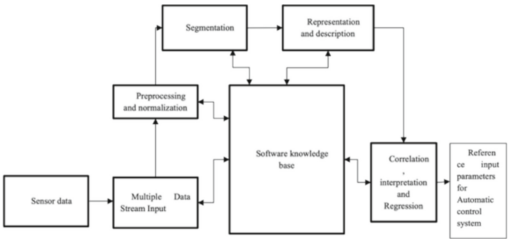

Fig. 7. Proposed data flow for knowledge acquisition

Data Acquisition

The input parameters are obtained from the sensors and control systems and included in the model. Once received, the entries are grouped and organized in the dataset. It is important to note that the system receives data permanently and organizes the results according to the harvest cycles and their timestamp. The reference output parameters given to the automatic control systems are updated in each cycle and are compared according to the speed of growth and the quality of the harvest. Quality, being a subjective parameter, will not be considered in this study and only the following parameters will be considered as parameters to be compared:

- Water Consumed
- Energy Used
- Time to harvest
- Crop Yield
- CO2 released

Data Mining
Once the complete data for each harvest cycle is collected, it is compared and inserted into predictive models to find patterns that optimize water and energy use, considering the time of growth and harvest. It is in consideration of this that the following specified algorithms are used to analyze growth and harvest time according to the literature.

Soil Quality / Water Flow

- ELMs with Radial Gaussiana [37]
- Neural Network AREF [37]

Growth
GoogleNet [38].
ResNet50 Model and an SVM Classifier [38].

Harvest
YOLO [39].

3.9 Simulation (4)

For the simulation, Acorn Land Labs Off Grid SIM was used for the crop growth and yield and CO2AI were used for the CO2 emission calculation. In addition, the figures were compared with the expected parameters according to the literature [40–42]. For this, the inputs and outputs were simulated to obtain the same number of products in traditional agriculture compared to aeroponics [43, 44]. In the successive comparisons of the simulation, the results obtained per harvest and per kilogram of the product are considered.

The base parameters of the simulation were given by suitable climates for harvesting. Wind is dismissed as a factor influencing the results as described by Fig. 8.

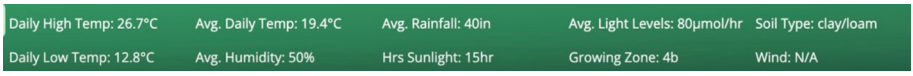

Fig. 8. Baseline parameters for climate and zoning for Acorn Land Labs Off Grid simulator

The simulation compares a standard aeroponic tower to a raised base harvesting system like that found in home gardens. Data associated with installation costs is not considered in the simulation, and only the results are considered. The input parameters are described as follows:

- Raised beds (24 sq ft)

  - Water: 100 gallons
  - Liquid fertilizer: 10 gallons
  - Seeds: 0.1 oz
  - Compost: 50 gallons
  - Soil: 30 lbs

The inputs of traditional agriculture are provided by Acorn Land Labs Off Grid SIM and are taken as the basis for obtaining the products. Given these conditions, the software indicates a yield of 8 lb of food per week.

The estimated labor time is based on the minimum needed to obtain a competent harvest. This estimate, according to the simulation is of 2 h setup and 1 h per week on maintenance.

The aeroponic tower only needs an initial input of water, which does not need to be refilled until after the first harvest cycle. This estimate is of 2 gallons only.

Aeroponic simulation considers each product separately so that the results of each one are then calculated, parameterized and the result repeated. This setup results in 10 lb of food per week with 2 h of setup and only 10 min of maintenance weekly.

One of the focuses of the development is to minimize the consumption of time invested, so the option that involves the least time dedicated to maintenance was sought and the initial installation value is disregarded as it is the same as traditional methods.

4 Computational Results

The results obtained by the traditional harvest are as expected and are aligned with the data obtained within the literature review. In addition, there is the notion of loss of nutrients due to shock of the plant when it is extracted from the earth and processed [45] (Table 3).

Table 3. Harvest yield for a cycle of each crop on a raised bed garden simulation

Produce	Kg of CO2	Timeto Harvest (Weeks)	Waterused weekly (liter)	Manhours weekly (Hr)	land requirement (m2)	Nutrients loss
Broccoli	0,54	8	126	1	1	30%
Lettuce	0,82	6	126	1	1	30%
Spinach	0,6	7	126	1	2	30%

Within the initial results for aeroponic cultivation, a marked difference in water usage and a decrease in emissions are observed. Also, the germination time for harvest is shorter. Aeroponic crops only generate CO2 emissions in relation to electricity consumption and future work should analyze the possibility of renewable electricity generation (Table 4).

4.1 Comparative Analysis

The results described show a reduction in water consumption of 85,1% and lower CO2 emissions, managing to emit only 0,27 kg of CO2 in relation to the 2.0 kg of CO2 per harvest with traditional methods. It is also important to consider that there is no loss of nutrients [45] and that the average harvest time decreases by one week , achieving

Table 4. Harvest yield for a cycle of each crop on aeroponic tower simulation

Produce	Kg of CO2	Time to Harvest (Weeks)	Waterused weekly (liter)	Manhours weekly (Hr)	land Requirement (m2)	Nutrients loss
Broccoli	0,09	7	18,7	0,1	0,3	0
Lettuce	0,09	3	18,7	0,1	0,3	0
Spinach	0,09	4	18,7	0,1	0,3	0

an improvement in the consumption of seminal water for each kilogram of products obtained in one square meter (Table 5, Fig. 9, 10).

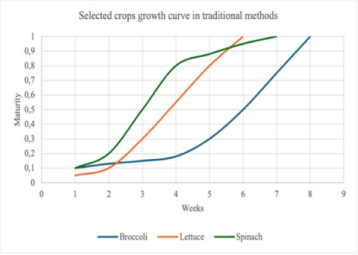

Fig. 9. Weekly simulated growth based on a maturity index correlated with projected size for raised bed.

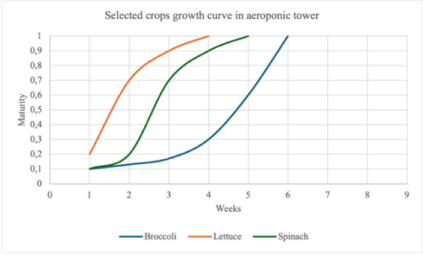

Fig. 10. Weekly simulated growth based on a maturity index correlated with projected size for aeroponic tower.

Table 5. Result comparison of yield, CO2 emission and water consumption between raised bed, aeroponic tower and optimized aeroponic tower

Method	Kgof CO2	Time to Harvest (Average weeks)	Waterused weekly (liter)	Nutrient Loss
Traditional	1,96	6	378,0	30%
Aeroponics	0,27	5	56,1	0%
Aeroponics Optimized	0,09	6	34,8	0%

When applying the optimization algorithms in the model a reduction in CO2 emission of 67% can be seen compared to the reference in part because of the optimization of light needed and the reduction in water pump workload. As such the water consumption weekly diminished from 7 L to 5 L which is a 29% reduction in water consumption. Nonetheless, the time to harvest metrics increased which is attributed to the availability of resources, which is a trade-off from the other parameters.

5 Conclusions

Aeroponic systems emerge as a groundbreaking and sustainable solution to pressing agricultural challenges. By significantly reducing water usage in 343,2 litters weekly (76% less compared to traditional methods) and minimizing space requirements (up to 90% less land needed), aeroponics paves the way for efficient cultivation even in urban environments and areas with limited arable land. This innovation not only fosters food security through increased yield per square meter and faster growth rates, but also contributes to economic prosperity and livelihood sustainability for farmers. Beyond resource conservation, aeroponics reduce the emissions of greenhouse gases by 343,2 kg less per yield, a 95% reduction in CO2 emissions by enabling local food production and minimizing transportation needs, making it a powerful tool for mitigating the environmental impact of agriculture.

The adoption of aeroponic systems for household vegetable cultivation offers a transformative approach to modern agriculture. This technology not only accelerates plant growth but also preserves essential nutrients, resulting in superior produce quality. The scalability of aeroponics allows for its application in communal and urban settings, converting unused urban spaces into productive vertical farms. Such integration can substantially enhance food and water security on a large scale, providing local, fresh produce while conserving critical resources. Moreover, the widespread implementation of aeroponic systems in urban environments could mitigate the carbon footprint associated with conventional agriculture and transportation, promoting sustainable practices and advancing urban food self-sufficiency.

While further research and development are crucial to optimize system performance, enhance scalability, and ensure accessibility for farmers worldwide, aeroponics holds immense promise for a future of agriculture that is more sustainable, resilient, and resource conscious.

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How to Reduce the Waiting List for Maxillofacial Surgery of Third Molars

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Abstract. The public healthcare system in Chile, specifically the Servicio Salud Metropolitano Sur Oriente, confronts substantial challenges resulting from lengthy waiting lists for maxillofacial surgery, affecting over one million residents. At the Centro de Referencia de Salud Hospital Providencia Cordillera, the demand for maxillofacial surgery exceeds the current capacity, with only two surgeons available to treat approximately fourteen patients per week. Despite recent efforts to augment the surgical team to four maxillofacial surgeons, the weekly patient capacity increased only to twenty-one, still insufficient to address the backlog. The primary objective of this study is to optimize the scheduling of maxillofacial surgeries to maximize the number of patients treated, taking into account varying levels of complexity and priority, without requiring additional resources. The scheduling problem was formulated as a job-shop model, and the optimization was performed using integer linear programming. The distinctiveness of this approach lies in its application to a critical public healthcare issue in a specific country and a specialized field. The model was evaluated using a sample of 500 patients, and the results indicated a significant reduction in waiting times, from fifty weeks to twenty-eight weeks - a 44% decrease - achieved solely through improved scheduling. These findings underscore the potential of operational optimization to enhance healthcare service delivery within existing resource constraints.

Keywords: Operating room planning · Optimization · Waiting Lists

1 Introduction

The growing demand for health services in Chile, with the insufficient resources and lack of specialists, generates waiting lists in various medical specialties [4]. In 2022, the waiting list for oral and maxillofacial surgery and traumatology reached 59.389 patients. Only in 1 of the six *Servicios de Salud* (SS) reach 18.571, particularly in odontology and maxillofacial surgery. In a *Centro de Referencia*

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(CR) of Servicio de Salud intervened, where the waiting list increases to 600 patients, it does not show that it is a public health problem that must be faced [5][?].

In literature, there are numerous developments that present models of management models and optimization of pavilions resources, that focus on how hospital resources are assigned [3][?]. This assignment can be made in different levels of decision. Some studies focus on date, hour and pavilion assignment for each patient and their respective interventions [2][?]. These studies imply a historical assignment of specialties to time blocks and wards. According to Wolff [7], his study should focus in optimizing the related processes with pavilions management, with the main objective of using resources and facilities efficiently.

Implementing this model could significantly improve resource management and reduce waiting list, positively impacting quality of life of patients. Likewise, the methodological approach, based on intervention complexity, could serve as a pilot to other health services in Chile. Those contributing to a better dental care in general on the country.

In the second section the formulation of the problem is presented. Subsequently, in the third section the design of the solution is presented and finally, the development and validation of the model/algorithm.

2 Material and Method

Data collection is carried thought Ley de Transparencia in collaboration with the unit of maxillofacial surgery of CRS HPC. The data collected will include surgery times, anesthesia, and cleaning of the operating room. The objective is to analyze the information and optimize the agenda of health professionals in maxillofacial surgeries of third molars, through input variables like complexity and times provides according to historical data of surgeries performed at CRS HPC.

The implemented model, corresponding to an optimization problem known in literature as scheduling with constraints specific with the problem [6]. The aim was to maximize the total quantity of attended patients. It was focused on a sample of 500 patients, and it was possible to demonstrate a reduction of waiting time by 44%.

The information was obtained by recording surgery times in the ward, where each patient was individualized. To develop the tests, the following surgical intervention parameters are used: preoperative time, surgery start time, surgery end time and cleaning time. From these data, the total duration of surgery is calculated, which consists of three phases: 1) preoperative time, 2) surgery and 3) postoperative time. In addition, the complexity parameters established by the health professional are obtained, as well as the number of molars, which was recorded at the end. The file was delivered in digital format, including the times of each professional involved in the process.

Finally, to obtain the total time per surgery, the type of complexity associated is defined:

- **Low complexity:** approximate duration of surgery from 0 to 19 min.
- **Medium complexity:** approximate duration of surgery from 20 to 29 min.
- **High complexity:** approximate duration of surgery from 30 min upwards.

The operation times for teams led by Dr. Diego Alcocer and Dr. Felipe Neira are presented in the Tables 1 and 2.

Table 1. Team 1: Dr. Diego Alcocer

Patient	*Complexity*	*No. of Molars*	*Preoperative Time*	*Surgery Start Time*	*Surgery End Time*	*Operation Duration*	*Cleaning Time*
1	Medium		00:06:00	09:30:00	09:52:00	00:22:00	00:03:00
2	Low		00:04:00	10:36:00	10:52:00	00:16:00	00:03:00
3	Low		00:05:00	11:19:00	11:35:00	00:16:00	00:03:00
4	Medium		00:04:00	12:04:00	12:28:00	00:24:00	00:03:00
5	Low		00:03:00	12:48:00	12:59:00	00:11:00	00:03:00
6	Low		00:03:00	13:20:00	13:29:00	00:09:00	00:03:00
7	Medium		00:03:00	14:33:00	14:56:00	00:23:00	00:03:00
8	High		00:03:00	15:13:00	15:49:00	00:36:00	00:03:00
9	Medium		00:03:00	16:00:00	16:21:00	00:21:00	00:03:00
10	Medium		00:03:00	16:39:00	16:59:00	00:20:00	00:03:00
11	Medium		00:03:00	17:21:00	17:48:00	00:27:00	00:03:00
12	Low		00:03:00	18:10:00	18:23:00	00:13:00	00:03:00

Table 2. Team 2: Dr. Felipe Neira

Patient	*Complexity*	*No. of Molars*	*Preoperative Time*	*Surgery Start Time*	*Surgery End Time*	*Operation Duration*	*Cleaning Time*
1	Medium		00:08:00	09:23:00	09:33:00	00:10:00	00:09:00
2	High		00:07:00	09:50:00	10:12:00	00:22:00	00:07:00
3	High		00:08:00	10:32:00	10:54:00	00:22:00	00:06:00
4	High		00:09:00	11:13:00	11:43:00	00:30:00	00:05:00
5	Low		00:08:00	11:59:00	12:09:00	00:10:00	00:03:00
6	Medium		00:09:00	12:29:00	12:42:00	00:13:00	00:06:00
7	Medium		00:04:00	13:00:00	13:21:00	00:21:00	00:07:00
8	High		00:07:00	14:20:00	14:49:00	00:29:00	00:06:00
9	Low		00:05:00	15:01:00	15:09:00	00:08:00	00:06:00
10	Medium		00:07:00	15:25:00	15:37:00	00:12:00	00:07:00
11	Low		00:05:00	17:05:00	17:15:00	00:10:00	00:08:00
12	High		00:05:00	17:35:00	18:01:00	00:26:00	00:07:00
13	Medium		00:09:00	18:20:00	18:32:00	00:12:00	00:08:00

3 Scheduling Algorithm Design

This section describes the three stages through which we can contribute to the reduction of waiting lists. First, the base scenario of the mathematical model is presented. Then the main constraints of the model and finally the mathematical formulation.

3.1 The Mathematical Problem Formulation is Based on this Scenario

The human team for any surgical intervention of a patient contemplates 1 maxillofacial surgeon, 1 Pavilion Attendant and 1 arsenal attendant. As for the planning of each team, it is weekly. Before each surgical intervention, a preparation process called "pre-surgical" is carried out. The process begins with the patient being admitted to the minor ward and positioned on the operating table. Intraoperative monitoring devices are then installed, followed by the administration of either truncal or infiltrative local anesthesia, depending on the surgical procedure. The surgical team sanitizes their hands, and both the surgeon and the assistant don sterile clothing. The surgical table is organized with all necessary instruments and supplies. Next, the patient's face is cleansed, and sterile drapes are placed over the operating fields to ensure a sterile environment. In the ward, the maxillofacial surgeon performs seven steps, as shown in the diagram in Fig. 1.

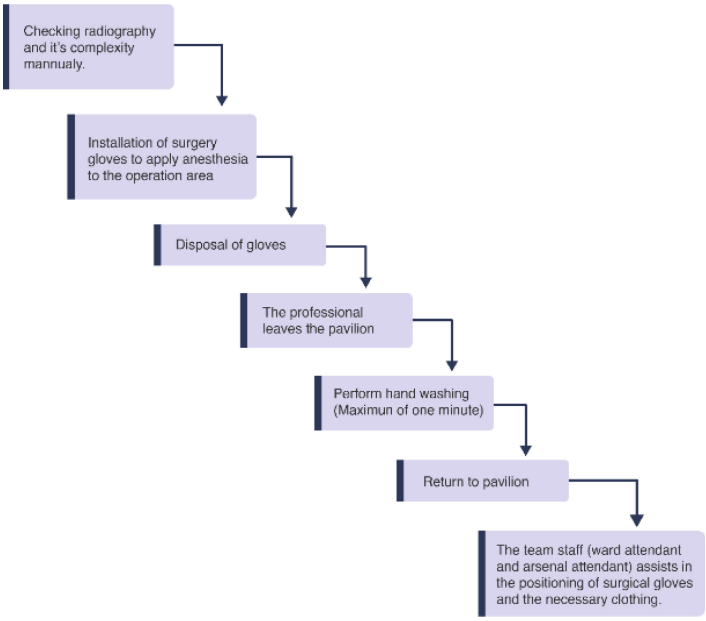

Fig. 1. Pavilion Protocol

Once the above is completed, the surgical procedure begins, the duration of which will depend on how many molars are to be extracted, and the review of the radiograph in situ and its complexity established according to its positioning.

After the surgery, when the last suture, mouth irrigation and placement of compression gauze is finished, the "post-surgical" process begins, where the ward attendant and the arsenal attendant clean the patient and prepare him/her to be discharged from the ward. While the maxillofacial surgeon gives medical instructions to the patient and/or delivery of a medical license if applicable (process lasts a maximum of 5 mins). Finally, the patient is removed from the ward and sanitization of the ward begins Immediately, which is performed by 1 auxiliary service (average duration of 3 mins).

3.2 Problem Restrictions

The maximum number of hours worked in the ward of a team is 12 h per week; the patient may have priorities according to their underlying disease. Therefore, it is required to maximize the number of patients who can undergo operations with low, medium, and high complexity. Patients may be prioritized if they have underlying diseases such as cancer in the area, coagulation problems, hypertension, type 1 diabetes, type 2 diabetes, among others.

3.3 Mathematical Model

The definition of the sets, parameters, decision variable and complete model generated to contribute to the reduction of waiting lists is presented.

Solution Set

- **PATIENTS:** Patient set $P = \{1, \ldots, p, \ldots, P'\}$
- **PATIENTS_ATTENDED:** Set of patients cared for within the set of patients.

Parameters

- $MaxWeeklyTime$: Time limit in minutes per week.
- $AttentionTime_p$: Time needed in minutes to care for the patient p.
- $Priority_p$: Patient care priority p. A higher value indicates a higher priority.
- $MinVarPriority$: Variable to store the minimum priority.
- $Limit$: Goal percentage (85% of 100%).

Decision Variable

- x_p: Binary variable that indicates whether patient p is treated (1) or not (0).

Objective Function and Constraint

$$\text{Maximize } total_patients = \sum_{p \in P} x_p \tag{1}$$

Subject to

$$totalTime = \sum (x_p * AttentionTime_p), \quad \forall p \in P \tag{2}$$

$$totalTime \leq MaxWeeklyTime \tag{3}$$

$$priority_p \geq MinVarPriority * x_p, \qquad \forall p \in P \tag{4}$$

The expression (1) is the objective function, which seeks to maximize the total number of patients served. The time used constraint (2) corresponds to the sum of all patients served. The time limit constraint (3) establishes the time limit per week per team, which cannot exceed the Maximum Week time. Finally, the priority constraint (4) corresponds to the fact that each patient has a value associated with it as a priority, the higher the priority, the first patient will be attended and so on until reaching 0.

4 Model/Algorithm Development and Validation

In this paper, a methodology is presented to address the medical care needs of patients with various levels of surgical complexity. Three differentiated cycles are developed, called Alpha Cycle, Beta Cycle and Gamma Cycle, which allow to attend efficiently and equitably all patients involved in the process shown in Fig. 2. The classification corresponds to the prioritization of patients, according to the result of their panoramic radiography complementing the previous work on *Predictive Treatment with Panoramic Radiographs of Third Molars*, which

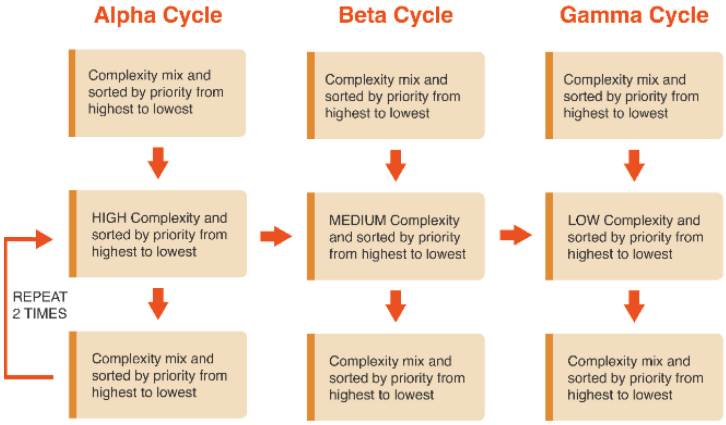

Fig. 2. Alpha Cycle, Beta Cycle and Gamma Cycle Methodology

explains that "*it is a routine examination requested by dentists to diagnose oral pathologies. The advantage lies in its cost, speed, and greater safety because digital formats allow reducing the dose and exposure times to radiation. Third molars can cause infectious problems and initiate benign or malignant tumoral processes. They also lead to neurological issues and can constitute zones of lower resistance to fractures due to their location in the bone. However, the main problem is the failure to timely identify the damaged molars and their presence, to be able to extract them. Thus, valuable time is lost that could be used to treat more patients and help reduce waiting lists in the healthcare network. The study aims to validate that, through panoramic radiographs, a machine learning system can be built to identify the inclination, depth, and available space of the molars, to support diagnosis and surgical approach*" [1].

The Alpha Cycle consists of two stages. In the first stage, a waiting list of 500 patients is managed, which includes all levels of complexity. The MIX ordering prioritizes patients according to the urgency of their care, without considering the complexity of their cases. The model processes this list and provides us with the number and sequence of patients to be seen. Once seen, these patients are removed from the waiting list.

The second stage of the Alpha Cycle focuses on high complexity patients who have not yet been seen. In this stage, a list containing only high complexity patients is processed, sorted by priority, from highest to lowest. This process is performed twice consecutively.

At the end of the Alpha Cycle, we move on to the Gama Cycle, which resumes the care of patients within the MIX order. Subsequently, it focuses on patients of medium complexity and, once their care is completed, it proceeds to care for patients of low complexity.

It should be noted that, at each stage where MIX ordering is mentioned, patients of all complexities are attended. This ensures that no patient is left without care until the end of the process. This methodology, divided into Alpha, Beta and Range Cycles, allows an efficient and equitable management of medical care, adapting to the different levels of complexity and needs of patients.

To compare the final results of this study, Fig. 3 shows the comparison between the two different scenarios for calculating the time required to attend a waiting list of 500 patients, with the aim of evaluating the efficiency of maxillofacial care and reducing waiting times. The first approach, which corresponds to the current situation, is based on treating 10 patients per week per medical team. Under this approach, it takes 50 weeks to see all the patients on the waiting list. The second approach uses a simulation that allows a variable number of patients per week per medical team. This methodology requires 28 weeks to see all patients on the waiting list, representing a 44% improvement in efficiency compared to the first approach.

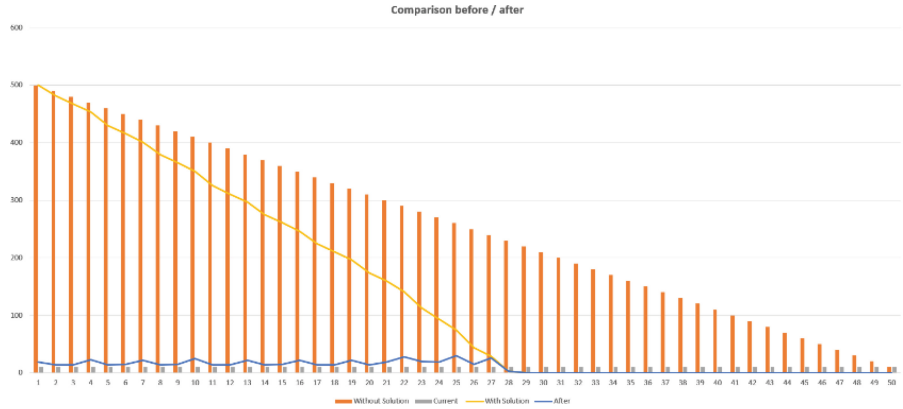

Fig. 3. Comparison Chart With and Without Waiting List Solution.

In summary, implementing simulation with a variable number of patients seen weekly can significantly improve efficiency in maxillofacial care. In this case, simulation would reduce the time required to see all patients by 44% compared to an approach based on a fixed number of patients seen per week. These results demonstrate the potential of simulations to optimize waiting list management and improve the quality of maxillofacial care in general.

In the graph Fig. 4, you can see that the orange and gray bars belong to the results without the solution and the yellow and blue lines correspond to the solution with the cut-off at week 28.

Tables 3 and 4 presents the outcomes of the alpha cycle for the initial four-week period, categorized by the urgency of care. This cycle incorporates various methodologies for diminishing the waiting list, including the MIX method, which amalgamates high, medium, and low complexities, prioritized accordingly. During the second and third weeks, primary attention is devoted to high-complexity cases, after which the cycle resumes with a combination of diverse complexities until all patients are cleared from the alpha cycle.

Table 5 and 6 presents the outcomes of the beta and gamma cycles over the past four weeks, wherein medium and low complexity cases receive priority. This cycle incorporates various methodologies for reducing the waiting list, including the MIX method, which combines medium and low complexities in order of priority. During the second and third weeks, solely medium complexity cases are addressed, after which the cycle resumes with a mix of diverse complexities until the depletion of all patients remaining in the beta cycle, at which point the process proceeds with the gamma cycle.

Table 3. Planning for the first four weeks.

1st Week (MIX)		
Patient	Att. Time	Priority
9	27	50
24	41	50
78	44	50
179	41	50
278	42	50
290	25	50
297	31	50
299	39	50
307	18	50
328	18	50
338	24	50
384	42	50
399	20	50
411	27	50
416	24	50
471	35	50
496	34	50
132	23	49
157	30	49
19	**585**	

2nd Week (High Complexity)		
Patient	Att. Time	Priority
134	27	49
192	41	49
248	44	49
443	41	49
291	42	49
473	25	48
42	31	48
171	39	47
337	18	47
444	18	47
16	24	47
156	42	46
181	20	46
14	**574**	

3rd Week (High Complexity)		
Patient	Att. Time	Priority
115	42	45
317	45	45
360	37	45
362	41	45
381	40	45
431	40	45
108	40	44
347	42	44
174	44	43
228	37	43
230	43	43
298	36	43
387	36	43
459	43	43
14	**566**	

4th Week (MIX)		
Patient	Att. Time	Priority
425	28	49
33	24	48
152	19	48
305	15	48
315	29	48
370	17	48
445	31	48
39	21	47
186	22	47
428	32	47
494	18	47
2	17	46
18	33	46
32	33	46
43	27	46
70	28	46
77	25	46
231	35	46
327	21	46
330	28	45
339	35	45
380	20	45
382	29	45
23	**587**	

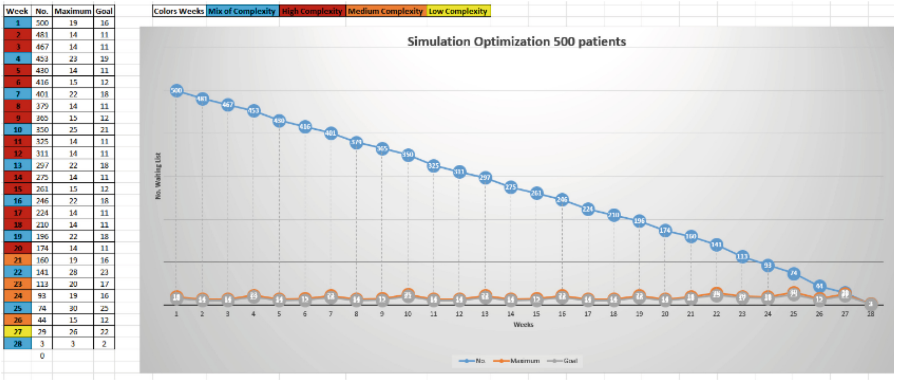

Fig. 4. Weekly Patient Care Chart by Complexity and Priority: Progress in Waiting List Reduction.

Table 4. Summary of interventions in the first four weeks.

1st Week	2nd Week (High Complexity)	3rd Week(High Complexity)	4th Week
Total Waiting List: 500	Total Waiting List: 185	Total Waiting List: 171	Total Waiting List: 453
Patients Attended: 19	Patients Attended: 14	Patients Attended: 14	Patients Attended: 23
85% of Patients Attended: 16	85% of Patients Attended: 11	85% of Patients Attended: 11	85% of Patients Attended: 19
Time: 585	Time: 574	Time: 566	Time: 587

Tables presents data from the first and last four weeks of a model designed to reduce the waiting list for patients in Chile. The model considers both priority based on patient morbidities and a mixed approach (MIX) to attend to patients with high priority but varying complexities (low, medium, and high).

Patients are assigned a priority level based on their morbidities, with higher numbers indicating greater priority. The "MIX" approach aims to balance the

Table 5. Planning of interventions with different levels of complexity.

25th Week (MIX)		
Patient	Att. Time	Priority
8	16	19
224	21	18
300	25	18
454	15	18
31	24	17
154	23	17
313	16	17
321	19	17
438	16	17
1	25	16
34	18	16
127	16	16
394	16	16
64	18	15
458	19	15
82	16	14
166	19	14
482	15	14
109	17	13
131	24	13
180	21	13
236	21	13
366	18	13
225	24	12
293	23	12
434	23	12
484	20	12
237	17	11
363	22	11
374	21	11
30	**588**	

26th Week (Medium Complexity)		
Patient	Att. Time	Priority
344	28	6
383	26	5
69	31	4
207	31	4
221	35	4
379	31	4
465	32	4
95	31	3
151	31	3
215	31	3
311	33	3
487	34	3
49	28	1
261	29	1
462	32	1
15	**463**	

27th Week (Low Complexity)		
Patient	Att. Time	Priority
65	16	10
195	16	10
310	19	10
348	15	10
107	25	9
116	21	9
286	19	9
436	21	9
464	24	9
272	16	8
342	19	8
110	21	7
148	19	7
390	25	7
106	15	6
239	23	6
486	22	6
135	20	4
184	22	4
424	25	4
111	20	3
7	20	2
80	20	2
144	25	2
147	24	2
345	23	2
26	**535**	

28th Week (MIX)		
Patient	Att. Time	Priority
255	15	1
350	21	1
435	24	1
3	**60**	

care given to patients with different levels of complexity while focusing on those with high priority.

Table 6. Summary of interventions with different level of complexity.

1st Week	2nd Week (High Complexity)	3rd Week (High Complexity)	4th Week
Total Waiting List: 500	Total Waiting List: 500	Total Waiting List: 500	Total Waiting List: 500
Patients Attended: 23	Patients Attended: 23	Patients Attended: 23	Patients Attended: 23
85% of Patients Attended: 16	85% of Patients Attended: 11	85% of Patients Attended: 11	85% of Patients Attended: 19
Time: 585	Time: 574	Time: 566	Time: 587

5 Conclusion

In conclusion, it is validated that process optimization in the field of maxillofacial care can generate significant results in terms of efficiency and quality of care. By using the ward close to 100% of its capacity, the existing infrastructure and human resources are used optimally, leading to significant improvements in timely patient care.

The implementation of these improvements made it possible to reduce the waiting list by 28 weeks instead of the manually planned 50 weeks. This represents a 44% improvement. It is expected to have positive consequences both for the prevention of other pathologies and for the reduction of morbidity associated with the delay in maxillofacial care.

Ultimately, the study demonstrates the importance of addressing optimization in public health care, not only as a matter of operational efficiency, but also as a key factor in improving the quality of life and health of patients.

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A New Efficient Genetic Algorithm for Solving the Kidney Exchange Problem

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Abstract. In the United States, renal complications rank eighth as the most common cause of death, creating waiting lists approaching 100 000 people, with only around 25 000 accessing kidney transplants. Faced with the challenge of meeting the total demand for necessary kidneys, renal exchange programs involving donors, recipients, and altruists have emerged, aiming to establish exchanges with chains or shortened cycles for logistical reasons. With the increasing prevalence of these exchanges and programs in both the United States and Europe, this paper presents a genetic algorithm designed to address them. This strategy is conceived to tackle larger instances, overcoming the limitations of conventional mathematical models reported in the literature. The application of this metaheuristic provides an effective and scalable solution, improving kidney allocation in the context of high demand and logistical constraints, offering responses to instances that cannot be addressed exactly.

Keywords: Metaheuristic · Genetic Algorithm · Chains and cycles · Donors and Altruists · Kidney Exchange Problem

1 Introduction

Organ transplants can be the only viable treatment for different types of diseases. These involve a medical procedure in which tissue or an organ from a donor is implanted into a recipient. The most advanced types currently are cardiac, cardiopulmonary, hepatic, pancreatic, and renal. The latter is the focus of this paper. In 2019, chronic kidney diseases ranked eighth among the most common causes of death in the United States, with 51 517 deaths, and in 2020, there were 48 141 deaths related to these diseases [4]. Not only is the high number of deaths concerning, but also one in seven American adults suffers from chronic kidney problems, and nine out of ten people are unaware they have this disease [3]. Despite treatments like dialysis being available, the most effective solution is kidney transplantation. However, this presents several challenges such

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as meeting the demand for this organ, properly prioritising transplants based on the patient's condition, and ensuring compatibility criteria between patient and donor for the transplant to be possible; hence, a long waiting list is generated [14].

For the year 2021, the number of patients on the waiting list for a kidney in the United States was 90 483, of which only 24 670 received a transplant, meaning only 27.3% were able to access this treatment [14]. On average, this waiting list grows by 3,000 patients every month, and a person can wait between 3 to 5 years on it. During this time, some patients deteriorate their health condition, making it difficult for them to receive a transplant or even leading to loss of life. On average, 13 people die waiting for a kidney transplant every day. In the year 2014 in the United States, 4 761 patients on the waiting list died, and 3 668 saw their health condition worsen while waiting, becoming ineligible for treatment [21].

On the other hand, the number of transplants performed has also shown an increasing trend in recent years [13]. These can be classified according to the type of donor into two categories: deceased or living, of which the former is the most common with a frequency of approximately double [13]. For the year 2017, a little over 5,000 transplants were performed from living donors, of which less than 1,000 correspond to those performed through kidney exchange, the remainder being through direct donations from deceased donors [14,22]. These exchanges are possible in centers that must be accredited by the Organ Procurement and Transplantation Network (OPTN) and must follow its policies and regulations.

In response to the growing demand for kidney transplants and the infeasibility of relying solely on waiting lists, the combinatorial problem known as the Kidney Exchange Problem (KEP) emerges [20]. Generally, the KEP seeks to pair the largest number of people so they can exchange kidneys. The literature has focused on studying mathematical formulations and analyzing their properties, but these approaches only provide solutions for small and medium-sized databases. For this reason, this paper addresses the design of an evolutionary metaheuristic and its evaluation for scalability on larger problems. The main contribution compared to other heuristic approaches in the literature is that the proposed algorithm does not require the exhaustive enumeration of cycles and chains, allowing it to solve larger problems.

2 Description of the Problem

One can become part of a kidney exchange program involving a KEP in two ways: cycles and chains. In cycles, each patient is required to enter with an incompatible companion who is willing to donate a kidney. Each pair (Patient - Donor) will exchange kidneys with another pair on equal terms (there is one patient and one incompatible donor). These exchanges must take place simultaneously to avoid regrets in donation, as transplants are voluntary. This condition of simultaneity requires the same number of available operating rooms as the number of pairs, usually limited to 4 exchanges in a cycle. The second form is chains, which involve

the existence of an altruistic donor as a starting point. This donor enters the program without any companion and selflessly donates their kidney to the first pair in the chain, and this pair will give it to the second, and so on, eliminating the restriction that cycles had regarding simultaneity [1].

In order to perform a transplant, the compatibility criteria between the donor and the recipient must be met, so that the patient's immune system does not reject the new organ. Among the main criteria are: blood group compatibility and tissue type. In the first, the patient must have the same blood antigen as the donor. Patients with antigen A will not be compatible with donors from group B, donors from group O, having no antigens, are compatible with all patients (ABO compatible), while patients of this blood group can only receive from another O. For the second criterion, compatibility must be based on Human Leukocyte Antigens (HLA). For this validation, the panel of reactive antibodies (PRA) is used, which helps identify tissue compatibility between patients who have already been found compatible by ABO [1].

The KEP presents challenges in decision-making regarding the allocation of pairs that will form cycles and chains. While the objective is clear, to maximize the number of transplants, as the number of pairs increases in the system, the number of incompatibilities also increases, generating greater complexity for the allocation. The KEP can be represented by a graph, where each pair of incompatibles is assigned a vertex (node), and each connection of compatible pairs is assigned an edge. The length of the cycles (cardinality) is usually limited to small values because most donor exchange programs perform procedures simultaneously to prevent the possibility of a donor withdrawing their commitment after the other donor has undergone the exchange [17]. In this case, the cardinality is limited to $2 \leq K \leq 4$ [9].

Figure 1 shows an example of an assignment in a problem with 16 pairs and 1 altruistic donor. The lightly shaded connections indicate possible exchanges, while the black edges represent actual assignments. In summary, pairs 15 and 3 form a cycle of 2 pairs, the altruistic donor (node 17) and pairs 4 and 8 form a chain of 3; finally, pairs 2, 10, 13, and 16 form a cycle of 4. In total, there are 8 transplants, leaving out another 8 people who do not receive a kidney.

3 Literature Review

Currently, kidney exchange programs have become one of the most relevant strategies to address organ shortages and increase transplant rates. These programs have evolved differently across countries and entities, each with its unique characteristics [17]. However, it has been found that limiting the length of chains to a cardinality of 4 produces better results compared to longer lengths [9]. The issue of multiple organ exchange has also been explored. For example, Dickerson and Sandholm propose a model for liver and kidney exchanges, encompassing both static configurations (with complete information from the beginning) and dynamic configurations (where not all nodes are available from the start). They adapt the Clearing Algorithm, a branch-and-bound based search to solve it.

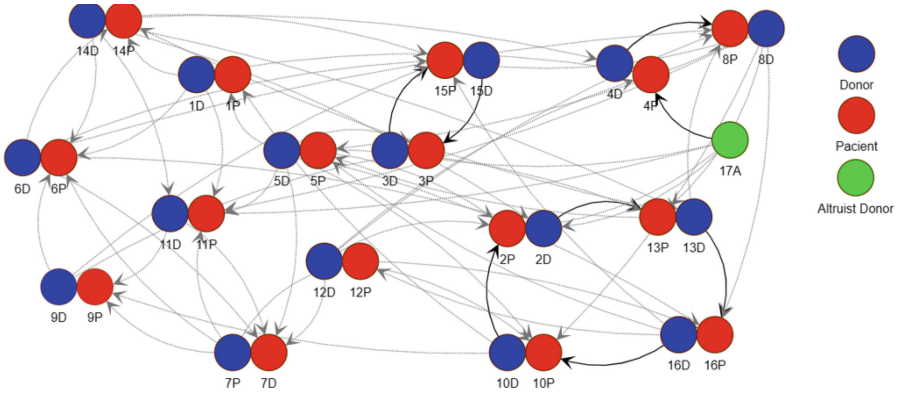

Fig. 1. Example of a solution for the KEP.

The largest instances consist of 1,000 pairs, and the results reveal that bi-organ exchanges significantly increase the number of achieved transplants; a direct relationship is also established between computing time, graph size, and the incompatibility rate [7]. Probabilistic variants of the problem have also been addressed, where the goal is to maximize the number of possible transplants considering the probability of a failure prior to surgery. Dickerson et al. introduce a mathematical model that includes failure probabilities for each connection (possible transplants), improving the expected utility of the matchings [10]. A branch-and-price algorithm is used for its solution, balancing overall efficiency and fairness for highly sensitized patients (those with a high level of antibodies against potential donors, making it difficult to find a compatible kidney). Simulations with real data show that this method significantly increases the number of successful transplants, improving both the efficiency and fairness of the system. However, the largest instances consisted of 1,000 pairs and 100 altruists, where the proposed exact approach, despite outperforming the commercial solver CPLEX, was not able to solve them.

Regarding the exact solution methods, Dickerson et al. address KEP which involves cycles, and chains of donations with bounded lengths. The authors present two new compact models based on integer programming: the position-indexed edge formulation (PIEF) and the position-indexed chain-edge formulation (PICEF), they also proposed a branch and price algorithm for solving them. The paper demonstrates that these new models are competitive and outperform existing solvers using real and synthetic data from national kidney exchange programs in the US and UK. These models are considered some of the most efficient to date and are a reference for comparison with new approaches [8]. Subsequently, Lama and Mak-Hau address the KEP as a Cardinality-constrained Multi-cycle Problem (CCMCP) without including altruistic donors. The authors propose a Branch and Cut and Price algorithm to solve it, which is compared against the state-of-the-art PICEF and PIEF formulations. Their results show that their program achieves optimal solutions in a limited time, significantly outperform-

ing the other evaluated approaches [18]. However, it is not able to solve problems with more than 2,048 pairs with a cardinality limit of 4.

The use of metaheuristics in the literature has been limited, as most articles focus on exact models. Mostly, works that include a metaheuristic approach are found in proceedings of academic conferences and in journals not indexed in SCOPUS or WOS. Among them, the work of Hamouda et al. can be highlighted, who propose the Ant Lion Optimization algorithm based on the hunting behavior of ant lions and their prey [12]. Although the results suggest that the algorithm is efficient, only test cases of 200 pairs are evaluated. It also requires extracting all possible chains and cycles, which is not feasible in realistically sized problems considering the NP-hard complexity of the KEP. A genetic algorithm was proposed by Goezinne in his master's thesis [11], the proposed encoding was a binary vector for each edge used in a solution. This can lead to infeasible solutions, as it does not guarantee the construction of closed exchange cycles. The author proposes an algorithm to create feasible solutions; however, since the search is completely random, it is highly inefficient. This problem extends to the crossover and mutation operators. Finally, Dababneh et al. propose another adaptation of a Genetic Algorithm that is divided into two phases: the first phase involves data preparation, and the second phase involves the execution of the algorithm [6]. The proposal is only tested on very small instances, being considerably efficient. However, this first phase again requires the exhaustive calculation of all possible cycles and chains.

Considering that exchange programs are growing, allowing the participation of patients from different countries and thus increasing the supply and the number of transplants performed, it is imperative to incorporate scalable search methods, such as metaheuristics, that do not require the exhaustive enumeration of the cycles and chains in the system [2]. For this reason, this paper proposes a new genetic algorithm, whose main contribution lies in the encoding and decoding, as it does not require such explicit enumeration.

4 Proposed Approach

This section details the design of the Genetic Algorithm (GA) proposed to solve the KEP. It is based on the principle of survival of the fittest, proposed by John Holland in 1975 [23]. The choice is based on a literature review, which found that population-based algorithms generally yield efficient results for this type of problem. The objective of the proposed algorithm is to maximize the assignments of pairs needing a kidney exchange, including cycles and chains. Without loss of generality, an equal importance factor (weight) will be considered for all edges. The design was developed considering the main considerations of the problem: a) altruistic donors are individuals who do not expect to receive a kidney, b) an altruist always initiates chains and does not need to close, c) cycles must always close, and d) cycles and chains have a maximum cardinality of 4 exchanges. The following describes the genetic operators as well as the stopping criterion and initial population.

4.1 Encoding

The encoding consists of the representation of a solution to the real problem stored in a computational container (such as a vector, list, or map), which is called a chromosome. The search of the algorithm will be conducted on the encoding, highlighting the importance of its definition. In this case, the literature has found encodings that exhaustively enumerate cycles and chains [6,11]. The main disadvantage is that this enumeration is not viable for large-scale problems because the number grows exponentially. Therefore, it was decided to define an encoding that does not require such enumeration, based on the graph representation $G = (V, E)$ of the problem, where V represents the vertices (pairs) and E the edges (compatibilities).

The main encodings used in problems also represented by graphs, such as the Traveling Salesman Problem (TSP) [19], the Vehicle Routing Problem (VRP) [5], or the Resource-Constrained Project Scheduling Problem (RCPSP) [15], consist of a list of activities or nodes whose order represents the priority for generating the solution. Thus, the proposed encoding is based on a priority permutation list and is represented by a chromosome composed of three vectors. The vector Vp stores a list of nodes (pairs and altruists) without repetition, whose order represents the priority for creating cycles (in the case of pairs) and chains (in the case of altruists). The second vector is Vk, whose genes are composed of integers between 1 and 4, representing the cardinality of the problem. This value is associated with the capacity to perform kidney exchanges simultaneously, which has been established at a maximum of 4, both for cycles and chains. The genes of Vk represent for each node in Vp the number of connections to make, indicating the size of the cycle or chain. Finally, there is the complementary vector Vt, which represents the type of donor for each gene in Vp, taking a value of 1 if altruist and 0 if it is a pair. Table 1 shows a complete chromosome for instance I.21 (detailed in Sect. 5.1). This consists of 18 nodes, of which 16 are pairs and 2 are altruists. For example, the first gene in vector Vp contains an allele with a value of 5, indicating the number of the pair that will be considered first to be assigned, and according to vectors Vk and Vt, it should generate a cycle ($Vt = 0$) of four ($Vk = 4$) connections.

Table 1. Example of a complete chromosome from the proposed encoding for the KEP.

I.21	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Vp	5	2	8	11	12	18	6	3	9	16	14	13	15	1	10	7	4	17
Vk	4	3	3	3	4	1	2	3	4	3	3	2	4	2	2	3	4	2
Vt	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1

4.2 Fitness Function (Decoding)

The decoding is the process of translating the encoded information from a chromosome so that it can be interpreted (calculating the fitness function value) and transformed into a real solution (which kidney exchanges to make). The proposed decoding is based on the Branch and Bound Algorithm (B&B), ensuring feasibility in all cases. The following describes it in detail based on the example in Table 1.

The assignment process begins by traversing the priority vector Vp with the pair $Vp[0] = 5$ and aims to generate $Vk[0] = 4$ connections, considering that the last one must return to the initial gene ($Vp[0] = 5$) since it is a pair ($Vt[0] = 0$) that must form cycles. This first decision is called level 0. At this point, the logic of (B&B) is applied, as if a return is not found in a given connection (i.e., a feasible connection without reaching the value of $Vp[0] = 5$), the algorithm must return to the corresponding previous level and search with the next node (feasible connection) until verifying if it is possible to close the cycle. For example, if with the first connection (pair $Vp[1] = 2$), pair 5 cannot obtain the four connections in any way (not even in later levels), then all other possible first connections must be explored, according to the explicit order of Vp. For instance, pair 5 has 11 possible recipients: 1, 2, 4, 7, 9, 10, 11, 13, 14, 15, and 16. But the first pair with which it should search for the cycle is the connection with 2 (following the order of Vp).

Returning to the example, since pair 2 is a compatible connection with pair 5, the first candidate for exchange is established, where pair 5 donates a kidney to pair 2, and the latter must continue the process to find to whom to donate their kidney. Finally, pair 2 must be added to the set *sReviewed*, which temporarily stores the already assigned nodes, to avoid taking previous nodes in the assignment. This second decision is referred to as level 1. Afterward, the vector Vp is traversed again from left to right, starting from the position following the last one that was reviewed. In this case, it would start from $Vp[2] = 8$ until finding a gene with a compatible patient and determining if this connection fulfills the available number of connections from Vk, or if it must continue searching at other levels.

Thus, since pair 2 is not compatible with pairs 8, 11, 12, 18, or 6, the next compatible node is at position $vp[7] = 3$, resulting in another exchange achieving $k = 2$ $(5 - 2 - 3)$ and at level 2. Then, the compatibility of pair 3 allows for assigning the kidney to $Vp[6] = 6$ (following the order of Vp and considering only unassigned nodes), achieving $k = 3$ $(5 - 2 - 3 - 6)$. However, since the initial node ($Vp[0] = 5$) is a pair, a cycle must be closed and returned to it. But pair 6 is not compatible. This forces the algorithm to backtrack to the previous level (level 1) and search, according to the order Vp, for a viable connection for pair $Vp[1] = 2$. If not found, it backtracks to the previous level to continue the search, and so on until closing the cycle or determining that $Vp = 5$ cannot have 4 feasible connections. Figure 2 shows the feasible cycle reached with this methodology, the chain is $5 - 2 - 16 - 3 - 5$. After closing the cycle or not, the process continues with the next node, and the process repeats until all nodes in

the Vp vector have been reviewed. Finally, for this example, this encoding has a total of 7 exchanges (Fitness Function): $(5-2-16-3-5)$; $(17-12-8)$ and $(18-1)$, and with respect to the size of the test case, a transplant completion ratio of 43.75% is achieved.

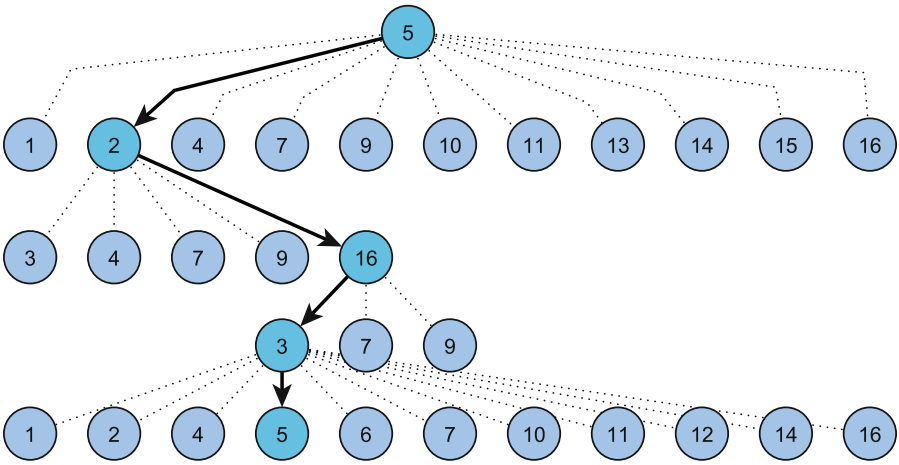

Fig. 2. Example of the decoding of a chromosome starting with pair 5.

4.3 Genetic Operators

Initial Population. This consists of the initial set of solutions from which the algorithm will begin its search. The initial population plays a very important role in the algorithm, as a sufficiently diverse one can assist the algorithm in the exploration phase by providing genetic variety [16]. It is usually recommended to construct the initial population with a random component, even when using a constructive heuristic, assigning priority values depending on a defined rule. In the proposed GA, an initial population is generated by assigning a uniform probability to the nodes: pairs and altruists. This probability is adjusted as nodes are scheduled, meaning that as more nodes are scheduled, the selection probability is adjusted (increased) according to the remaining nodes and eliminating those already assigned, to avoid repeated nodes.

Selection Operator. This is the process of selecting parents who will subsequently reproduce and create offspring. This operator should encourage the inheritance of the best genes to produce better individuals, but without being completely elitist [16]. In this algorithm, roulette wheel selection based on the fitness of the chromosomes was chosen [23]. For this, the fitness function was normalized with respect to the sum of the fitness function values of the current population. The possibility that a selected solution can reproduce with others,

i.e., selection with replacement, is considered. This allows the fittest solutions to have a higher probability of generating offspring with multiple pairs.

Crossover Operator. The main idea of crossover is to combine genes from individuals, potentially creating offspring with superior characteristics. However, even if the offspring have lower fitness than the parents, it does not mean a setback because these offspring may contribute valuable genes for future generations [23]. For this project, the one-point crossover adapted for permutation problems (which do not allow gene repetition) was selected. The process begins with selecting the parents and randomly generating a crossover point (a position in the vector). Then, the genes from the father are added up to the crossover point. Finally, genes that are already in the offspring are discarded from the mother's chromosome, and the remaining genes from the mother are added in the explicit order of their Vp. This is illustrated in Fig. 3.

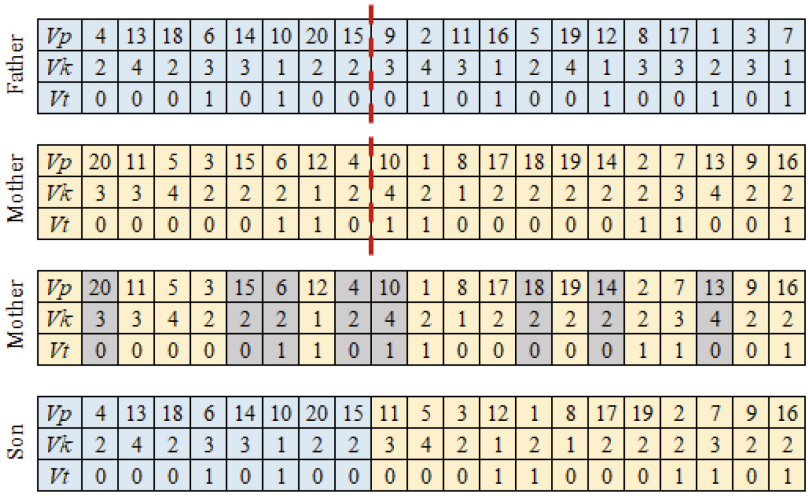

Fig. 3. Example of the one-point crossover operator.

Mutation Operator. Mutation randomly alters the value of one or more genes of an individual with a predefined probability. This operator mimics the natural process where small errors can occur in the genetic transfer from parents to offspring, and sometimes these errors lead to genes beneficial for survival. The mutation probability is usually very low since mutations can often decrease the fitness of the population (it promotes exploration but limits exploitation) [16]. For the proposed GA, the genetic exchange mutation was adapted, which involves selecting two genes at random and swapping their positions (including all three vectors defined in the encoding).

Replacement Operator (Survivor Selection). This phase determines which individuals will be retained for the next generation. It is important that the fittest individuals are not removed from the population while maintaining diversity within the population. Some GAs use elitist strategies, ensuring that the current fittest member of the population always propagates to the next generation. In other cases, the simplest policy is to randomly remove members from the population or use the offspring as the new population. In this algorithm, a semi-elitist survivor selection strategy will be implemented. This involves retaining 10% of the top-performing solutions from the parents and 10% of the best offspring. This practice aims to preserve and elevate the quality of individuals in successive generations. For the remaining population, new solutions will be generated randomly. This reintroduction of solutions aims to promote exploration in new areas, avoiding stagnation in local optima.

Stopping Criterion. This defines the mechanism to stop the search. Often, a GA runs for a predefined number of generations. This can be reasonable in various experimental settings. On the other hand, the time and cost of evaluating the fitness function can limit the duration of the optimization process. In our case, specifically, one of the stopping conditions is time, as the B&B approach of the decoder may require significant computation time; thus, a maximum time limit of 30 min is set.

5 Computational Results

This section presents the results obtained from implementing the proposed GA. The experiments are run on a PC with 2.5 GHz Intel(R) Core(TM) i5-10300H, and 8 GB of RAM, the GA was complied in C++. First, the test cases used are detailed (Sect. 5.1), then the parameterization is described (Sect. 5.2), and finally, the results are summarized (Sect. 5.3).

5.1 Instances

The various studies addressing the KEP use a reference dataset library called *Kidney Data (00036)* from the PrefLib repository. This was proposed by John Dickerson in 2013, and consists of 310 cases of kidney donors. The database contains simulated information about patients and donors involved in kidney exchanges. Specifically, the library has a set of 10 randomly generated data instances of kidney exchanges with 16, 32, 64, 128, 256, 512, 1024, and 2048 nodes (pairs), with a proportion of altruists ranging from 0%, 5%, 10%, to 15% of the set. Each set has around 40 test cases except for the set with 16 nodes, which has 30. The library is available at https://preflib.simonrey.fr/dataset/00036.

5.2 Parameterization

For the parameterization, a study based on the Taguchi methodology in MiniTab was carried out, focusing especially on medium-sized cases. The parameters considered were the initial population size, the number of generations, and the mutation probability. These parameters were considered at three levels to evaluate their impact on the response variables, specifically, the number of exchanges and computation time. This methodology establishes nine combinations to execute (Table 2). The test cases used were four with 256 pairs with 0, 12, 25, and 38 altruists, and another four test cases with 512 pairs with 0, 25, 51, and 76 altruists, respectively.

Table 2. Experiments and parameters to use according to the Taguchi methodology.

Gen	Pop Ini.	% Mut
15	15	5%
15	20	8%
15	25	10%
20	15	8%
20	20	10%
20	25	5%
25	15	10%
25	20	5%
25	25	8%

The results suggest that for the number of generations and the initial population size, the choice is 25. Although the mutation does not reach statistical significance, Taguchi shows that with a probability of 10%, the best results were achieved. These results were obtained with the response variable: number of exchanges performed. The adjustment value (R-squared) was 99.10% for test cases of size 256 pairs and 98.16% for cases of 512. Additionally, a numerical classification of the parameters was conducted, assigning the highest value to the parameter that exhibits the most significant impact on the results. Both for test cases with 256 pairs and with 512 pairs, a consistent pattern was observed, where the determining factor is the number of generations, occupying the highest relevance. From this perspective, it is suggested that to improve results, efforts should be focused on the parameter of generations, followed by the initial population, while the mutation probability ranks last in terms of impact. For the larger and smaller instances, the same behavior pattern was followed and adjusted according to a trade-off between computation time and the number of exchanges. The problems were thus categorized into three scales: small (less than 128 nodes), medium (less than 512 nodes), and large (more than 1024 nodes). In the small category, an initial population of 100 chromosomes and 50 generations

were used; in the medium category, 20 chromosomes in the initial population and 20 generations were employed; finally, for the large category, 6 chromosomes were used as the initial population and 5 generations.

5.3 Obtained Results

Table 3 presents a comparison between the mathematical model PICEF (available in [24]) and the proposed GA, using data from the Kidney Data (00036) library [9]. The first column (P,A) indicates the number of pairs and altruistic donors in the instance, the second and fourth columns show the average number of exchanges achieved (Z) for the GA and PICEF, respectively, the third and fifth columns present the average number of seconds (T) taken by the GA and PICEF, respectively; finally, the last column shows the variation between both methods, where a positive value indicates a higher proportion achieved by PICEF. Each row of the table represents the execution and average of a set of 10 instances of the corresponding size P,A.

Table 3. Comparison of results obtained by GA and PICEF.

P,A	Average GA Z [number]	Average GA T [s]	Average PICEF Z [number]	Average PCIFE T [s]	Variation Z GA vs PICEF [%]
16,0	4,60	1,35	4,60	0,00	0,00%
16,1	8,80	1,66	8,80	0,01	0,00%
16,2	9,70	1,74	9,70	0,01	0,00%
32,0	17,60	5,94	17,70	0,03	0,50%
32,1	17,50	6,28	17,50	0,05	0,00%
32,3	21,10	6,65	21,10	0,05	0,00%
32,4	23,00	6,93	23,00	0,06	0,00%
64,0	36,60	31,77	37,60	0,26	2,71%
64,3	41,40	34,83	41,80	0,37	0,93%
64,6	41,50	37,63	41,60	0,32	0,24%
64,9	48,10	40,72	48,30	0,34	0,35%
128,0	76,20	215,89	78,80	4,51	3,23%
128,6	89,50	235,46	90,50	8,03	1,03%
128,12	89,70	253,72	89,90	5,70	0,23%
128,19	104,30	263,32	104,60	6,69	0,29%
256,0	153,80	140,50	163,60	160,55	6,00%
256,12	175,50	143,81	180,70	164,57	2,84%
256,25	187,90	150,67	190,60	165,65	1,41%
256,38	197,70	162,61	200,60	127,04	1,44%
512,0	308,70	1334,33	OM	OM	OM

continued

Table 3. continued

P,A	Average GA Z [number]	Average GA T [s]	Average PICEF Z [number]	Average PCIFE T [s]	Variation Z GA vs PICEF [%]
512,25	349,50	1416,83	OM	OM	OM
512,51	378,40	1311,25	OM	OM	OM
512,76	402,60	1416,21	OM	OM	OM
1024,0	618,90	1317,09	OM	OM	OM
1024,51	687,10	1286,51	OM	OM	OM
1024,102	755,90	1228,33	OM	OM	OM
1024,153	790,80	1098,41	OM	OM	OM
2048,0	1207,00	17795,40	OM	OM	OM
2048,102	1352,00	17308,60	OM	OM	OM
2048,204	1481,00	15406,80	OM	OM	OM
2048,307	1608,00	10630,00	OM	OM	OM

OM: Out of memory

In the small and medium test cases, the maximum percentage variation of Z relative to the PICEF model was 3.23% and 1.13%, respectively. This indicates that the proposed GA is capable of finding near-optimal solutions. On the other hand, a considerable difference in time is observed in percentage terms in favor of the PICEF model in small cases. However, these differences do not translate into significant time units; they represent only a few additional seconds, depending on the instance size. For example, in instance 30, PICEF took 0.011 s and the GA took 1.881 s, indicating a difference of 1.87 s. Thus, these differences are considered imperceptible in practice. In the medium cases, a decrease in the percentage variation in time is observed. This indicates that as the number of nodes increases, the proposed GA starts to match the PICEF mathematical model in terms of time and even surpasses it from 512 nodes onwards, where the mathematical model reaches its memory capacity limit (OM). In the large test cases, PICEF did not generate any results, while the GA did.

6 Conclusions

In this paper, we addressed the Kidney Exchange Problem (KEP), which arises from the complex kidney exchange programs that have emerged in the United States, Canada, and Europe. These programs are a response to the long hospital waiting lists, where patients die each year waiting for a transplant. Multiple medical, ethical, and social facets of this problem were identified, highlighting the need for innovative solutions to overcome inherent challenges, such as maximizing exchanges while considering compatibilities and cardinality. The scientific literature has categorized the problem as NP-Hard, which makes it difficult to solve, and given the growing demand for these programs, which seek international integration, the need for methodologies capable of solving large instances is evident.

The relevance of this project is reinforced by the fact that previous research has mainly focused on mathematical models to solve the KEP, with limitations in solving large cases. Moreover, the exploration of metaheuristics in the literature has been limited. Thus, in this work, we designed a Genetic Algorithm (GA) whose main contribution is that it does not require the exhaustive enumeration of the cycles and chains of the problem, unlike the proposals found in the literature. The proposed GA incorporates a coding and decoding scheme that adapts the logic of Branch and Bound to ensure feasibility and efficiency when evaluating a solution. Additionally, an adaptation of the genetic operators compatible with this coding is proposed.

Regarding the experimental results, the proposed GA was compared with the state-of-the-art PICEF formulation using the Kidney Data (00036) library. It was not compared with other metaheuristics in the literature because no algorithms have been reported for large instances (greater than 512 nodes). The GA achieved promising results, with a deviation of 1.12% from PICEF in the instances where the mathematical model reported a solution (up to 256 nodes); for larger instances, the model exceeded the computer's memory capacity. On the other hand, the GA managed to find solutions in these cases with average times of approximately 1 h in the worst cases. On average, the percentage of exchanges achieved by the PICEF formulation was 66.68% for problems from 16 to 256 nodes, while the proposed GA achieved a percentage of exchanges of 67.36% for problems from 16 to 2048 nodes.

As future work, we plan to combine the GA with other metaheuristics, such as ant colony optimization, simulated annealing, or particle swarm optimization, to increase efficiency in larger instances. Additionally, new codings could be defined that do not require branching or even allow infeasible solutions with penalties. Furthermore, we aim to explore synergies that could improve the efficiency and quality of the solutions through hybridization with exact methods.

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Network Emulator Based on Openstack for the Implementation of a Virtual Data Network Laboratory in Higher Education Institutions

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Abstract. Nowadays, networks are indispensable tools for the development of new technologies such as cloud computing, big data, the Internet of Things, among others. Therefore, it is necessary to explore new tools that allow improving the understanding and practical skills of students in the field of networks. This document presents a web application based on OpenStack, which allows for the emulation of physical network laboratories through the virtualization of components, as it partitions physical resources to provide access to more users. For this, some Openstack services were used in conjunction with VirtualBox. Additionally, validation was conducted through end users, and the results obtained showed that 94% of expert teachers and 95.8% of surveyed students highlighted the utility of the application, while 78% of teachers and 91.5% of surveyed students emphasized the usability of the developed application. These results demonstrate the potential of the application to be implemented in a virtual laboratory of a networking course and take advantage of the available technological resources.

Keywords: emulator · networking · openstack · virtual laboratory

1 Introduction

Currently, society is governed by the digital world, as information technologies and cloud computing increasingly provide people with convenience in their daily lives, but also expose them to more vulnerabilities on the network [1]. Therefore, networks, in their multiple fields, transcend the academic sphere to become an essential skill in the world of engineering, therefore, it is fundamental that curricular plans offer effective network courses to train their students [2]. On one hand, for many universities, it is difficult to create and maintain updated laboratories with physical equipment that provide experiences close to real environments, as they lack the necessary financial resources [3]. Indeed, in response to the challenge presented, [4] proposes a low-cost and easy-to-handle IoT laboratory, which takes advantage of widely available software and cloud platforms. In

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addition, an educational project called 'Lab-Tec@Home' is presented, which consists of an affordable laboratory kit that students can assemble at home. This project has proven to be effective, as it improved the learning experience of undergraduate students [5]. On the other hand, in academic programs with network subjects, many universities use computer network simulators, which allow simulating various network devices and running a greater number of experiments [3]. However, article [6] indicates that the engineering experience of students using simulators is lower compared to direct manipulation of equipment. This document presents a tool called "OstackNET-Emulator" that allows teachers to emulate network scenarios and students to access their components.

This paper is organized into the following sections: Sect. 2 discusses related work. In Sect. 3, the methodology and technical aspects of the solution are explored in depth. Section 4 describes the validation procedures employed for the solution. Section 5 presents the findings obtained from the surveys. Section 6 presents the discussion. Finally, Sect. 7 presents the conclusions.

2 Related Works

In this section, we review some of the existing network emulators and their applications in virtual laboratories. In the article [7] to provide students with an experience like that obtained from a test bench, a cloud-based wireless network emulator was developed. To achieve this, they leveraged the emulation capabilities of NS-3 [8], which allow for the easy recreation of diverse scenarios. The authors conclude that the use of the tool improves the understanding of the wireless networks course. In [9] ViRe-Lab is proposed, a virtual remote laboratory focused on cybersecurity teaching, which takes advantage of virtualization paradigms and the cloud to generate various emulated environments. Furthermore, it was integrated into the practical curriculum of a cybersecurity course, in which students can perform various activities, as it is built upon technology EVE-NG [10]. The results obtained demonstrate high levels of student satisfaction and acceptance when using this tool. In [11] a communication network emulator called ComNetsEmu is presented, which takes advantage of the capabilities of the Mininet [12] network emulator to enable its SDN functionalities. This tool is implemented as an independent virtual machine that integrates an SDN network emulator (Mininet) with an NFVI solution (Docker). In [13], a high-performance routing emulation technology is proposed that merges software-defined networking (SDN) technologies and OpenStack [14], which is open-source and flexible. Experiments demonstrate that, compared to other technologies, this approach achieves lower overhead and higher performance for routing nodes. Finally, thesis [15] presents a high-fidelity network emulator to analyze the behavior of emerging technologies. However, although it does not have an educational focus, the thorough analysis of existing network test environments, virtualization technologies and the Cloud Computing platform (OpenStack) was a relevant theoretical basis for this project.

3 Method

3.1 Solution Components

The proposed solution is a web application that emulates a physical network laboratory environment of a higher education institution through the virtualization of com-ponents such as computers, switches, and routers. This was achieved using the open-source software OpenStack, which offers a modular system composed of various computing, networking, image storage, security services, etc. In Table 1, the critical services of OpenStack [16] essential for the operation of the application are detailed.

Table 1. Openstack Services

Service	Description
Keystone	It manages the authentication of users and authorization to all the infrastructure of OpenStack
Nova	It manages the creation of instances (virtual machines), providing control over the infrastructure
Neutron	Manages the network through connectivity services between virtual devices
Glance	Provides storage and deployment of operating system images used by the instances

On one hand, to use OpenStack technology, the modules (services) had to be installed on two virtual machines with different characteristics created in VirtualBox. Firstly, the essential services such as Keystone, Glance, Nova (controller part) and Neutron (controller part) were hosted on the virtual machine called 'controller'. In other words, this virtual machine determines which application service will be executed and how it will be carried out. Secondly, in the other virtual machine called 'compute', the Nova (executing part) and Neutron (executing part) services were deployed to manage computational resources. This means that here the services requested by the user are executed. It should be noted that more than one 'compute' virtual machine can be created, which improves the capacity and performance of the web application. Additionally, to facilitate the interaction between the local computer (host) and the OpenStack services, port forwarding configuration was implemented on each VirtualBox virtual machine. In other words, through this configuration, virtual machines can be accessed from the Command Prompt (CMD) of the local computer (host) via an SSH connection. This form of access made it easy to verify whether the creation of topologies, virtual machines, etc., were successfully carried out. In other words, through the pre-established OpenStack commands, it was possible to evaluate the correct functioning of the created topologies. For example, to verify that a topology has been created correctly in the application, one can observe the status of the virtual machines that comprise it, the network and subnet links, as well as verify that the images and capacities have been correctly assigned (see Fig. 1).

On the other hand, the development of the application was carried out using Django, a robust and scalable server-side backend framework based on Python. While the user

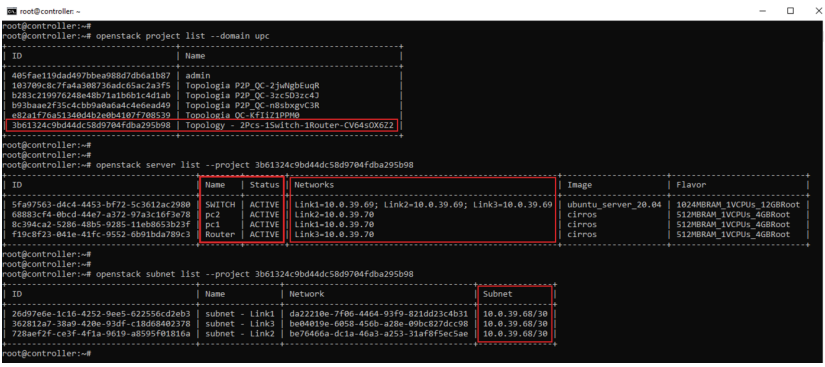

Fig. 1. Virtual Machine 'controller' from the CMD

interface was made with Bootstrap, a frontend framework that provides various components in Html, Css, and JavaScript, which facilitated the creation of the app. It is worth noting that the communication between the application′s backend and the OpenStack APIs was carried out through an organized and coordinated process. That is, through HTTP requests, the backend sends requests to the OpenStack APIs, such as Nova, Neutron, Glance, and Keystone, depending on what the user has selected in the application interface. These requests contain the necessary information to perform actions such as topology management, virtual machine creation, network configuration, image management, capacities, and identity services. The response from the OpenStack APIs is processed in the backend and then, the updated interface of the application is displayed in the frontend based on the request made. This bidirectional and secure flow between the backend and the OpenStack APIs allows the web application to leverage the power, flexibility, and capability of OpenStack to provide efficient and scalable services to end users. These users are made up of teachers and students enrolled in a basic and intermediate level networking course at a higher education institution, who will have access to the application through a computer with an Internet connection. The main components of the application′s physical architecture are outlined below for better understanding (see Fig. 2).

3.2 Web Application

It was developed with the aim of being executed within a virtual network laboratory belonging to a higher education institution. This application simplifies the creation of virtual environments so that users can subsequently access their components and configure them. The users directly linked to the application are the teachers in charge of the laboratory and the participating students. Below is an explanation of these users' interaction with the application. On one hand, the teacher is responsible for designing the virtual environment (they are called 'temporal topologies' in the app). In this section, the teacher must specify what and how many components are required for the topology they wish to create. After completing this activity, they must also indicate how the components relate to each other. To do this, they must establish the links, which indicate the structure of the topology to be created (see Fig. 3).

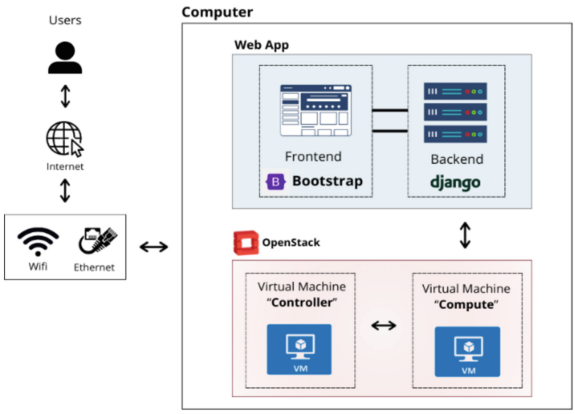

Fig. 2. Physical architecture

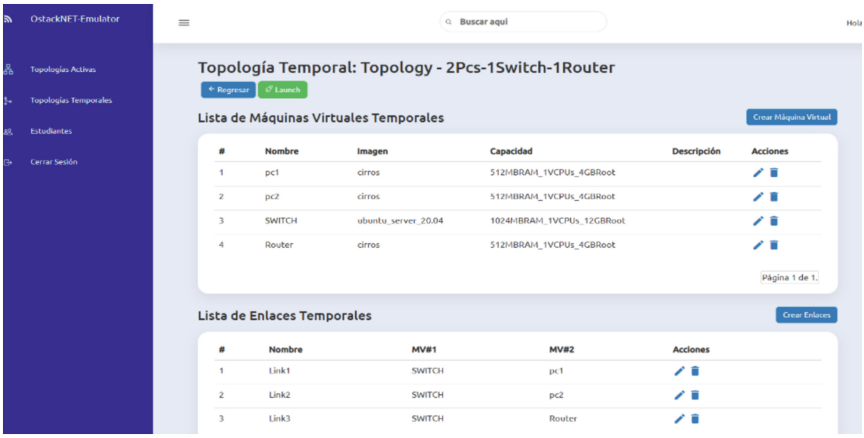

Fig. 3. Interface for designing a virtual environment.

On the other hand, after the teacher has created and assigned the required topologies to the students, they can already start activities in the application. Once inside the app, they can view the list of topologies created by the teacher, as well as the virtual machines and links associated with each topology. In addition, to configure a topology proposed by the teacher according to the topic to be discussed in the laboratory (static routing, dynamic routing, intervlans, etc.), students will be able to access the console of each virtual machine to configure IP addresses, routes, etc. They can do this through the laboratory guides that accompany the application, which provide a step-by-step process for configuring a topology.

4 Validation

The quality of a web application can be measured based on metrics applied to the network, the application server, client responses, and end-user surveys [17]. Therefore, for the validation process, user satisfaction was considered, through a survey conducted with teachers and students based on the Likert scale. This scale uses different levels of measurement, which are: Strongly agree, Agree, Undecided, Disagree, strongly disagree. To obtain a final percentage for each indicator, each level of the scale is assigned a score from 1 to 5, where the maximum score (5) is associated with the response 'Strongly Agree' and the minimum score (1) with 'Strongly Disagree'.

$$Ans = \left(\frac{Sum(Scores\ per\ question)}{\#\ surveyed\ users * 5} \right) * 100$$

- Ans: Answer in percentage

The survey was conducted with 5 expert teachers in networks and 10 students from the Systems Engineering and Software Engineering programs at UPC[1], who had previously taken a course in networks and data communications in their program. Below is a more detailed profile of the experts.

1. Network and Data Communication Professor at UPC.
2. Computer Networks Teacher, Faculty of Science and Engineering, Telecommunications section, PUCP[2].
3. CCNA Instructor and NSE4-Fortinet Network Security Professional, Continuing Education PUCP.
4. Computer Networks Teacher, Faculty of Science and Engineering, Computer Science section, PUCP.
5. Instructor of Cloud Network Engineering and Software-Defined Networking, Faculty of Science and Engineering, Telecommunications section, PUCP.

On the one hand, based on the questions from the survey conducted with teachers, Table 2 shows the necessary indicators to validate the proposed solution based on the teacher user. These indicators were formulated to measure the utility and usability of the application based on a percentage.

On the other hand, Table 3 displays other indicators focused on the student user. These were generated based on the questions from the survey conducted with the students.

[1] Peruvian University of Applied Sciences.
[2] Pontifical Catholic University of Peru.

Table 2. Teacher survey indicators

#	Indicator	Target
1	Utility for a Network Laboratory	Demonstrate that the utility of the application has an average greater than 75% rating
2	Complement to traditional teaching materials	Demonstrate that more than 75% consider it a good complement to traditional materials
3	Resource for Networking Students	Demonstrate that more than 70% of experts consider the application to be a good resource for students
4	Learning experience	Demonstrate that more than 75% of teachers indicate that it offers a good learning experience
5	Complementary resource for networking courses	Demonstrate that more than 75% of experts consider it a complementary resource for networking courses
6	Ease of use and visual appeal	Demonstrate that more than 70% of experts rate the application as easy to use and attractive

Table 3. Student survey indicators

#	Indicator	Target
1	Complement for Network Classes	Demonstrate that more than 75% of students consider it a complementary resource for networking classes
2	Development of Practical Skills	Demonstrate that more than 75% of students consider that the app will help them develop their practical skills
3	Learning experience	Demonstrate that more than 75% of students consider that the application offers a positive educational experience
4	Recommendation to Other Students	Demonstrate that the application is recommended by students in a percentage greater than 75%
5	Ease of Use and Visual Appeal	Demonstrate that more than 70% of students rate the application as easy to use and visually attractive

5 Results

5.1 Expert Teachers

Firstly, based on the survey carried out among the experts, the following results were obtained for each proposed indicator, see Table 4.

Table 4. Result of Indicators from the teacher survey

#	Indicator	Target
1	Utility for a Network Laboratory	86% of experts consider that the web application would be useful for a network laboratory
2	Complement to traditional teaching materials	96% of respondents consider that it is a good complement to traditional teaching materials
3	Resource for Networking Students	96% of experts indicated that the application would be a good resource for their students
4	Learning experience	96% of respondents indicated that the app would offer a good learning experience
5	Complementary resource for networking courses	96% of experts consider that it is a good complement to networking courses
6	Ease of use and visual appeal	On average, 78% of experts indicate that the application is easy to use and visually attractive

5.2 Students

Secondly, based on the survey carried out with the students, the following results were obtained for each proposed indicator, see Table 5.

Table 5. Result of Student Survey Indicators

#	Indicator	Target
1	Complement for Network Classes	93.33% of students indicate that the app is a good complement to their networking classes
2	Development of Practical Skills	96.66% of students indicated that the application would help them improve their practical networking skills
3	Learning experience	96.66% of students consider that the application offers a positive experience in their education

(*continued*)

Table 5. (*continued*)

#	Indicator	Target
4	Recommendation to Other Students	96.66% of respondents indicated that they would be willing to recommend the application
5	Ease of Use and Visual Appeal	It was shown that on average 91.5% of students indicate that the application is easy to use and visually attractive

In addition, grouping the user indicators according to the usefulness of the application and ease of use, we obtain the results in Table 6.

Table 6. Summary of results

User	# Indicator	Metrics	Result
Teacher	1, 2, 3, 4, 5	Utility	94%
	6	Usability	78%
Students	1, 2,3,4	Utility	95.8%
	5	Usability	91.5%

6 Discussion

This research work presented a network emulator called 'OstackNET-Emulator' that achieved a utility percentage higher than 90%, as well as a rate higher than 75% in terms of its usability according to the teachers and students surveyed. This positive result reflects the users' acceptance of the application′s utility and ease of use. Additionally, the ongoing creation of new emulators highlights that, although similar tools exist in the market, there is a continuous pursuit to develop more customized solutions tailored to the specific needs of educational or business environments. However, it is recommended to increase the sample size of surveyed users in future studies to obtain more solid and representative results.

7 Conclusions

In conclusion, the web application "OstackNET-Emulator", which allows creating a virtual infrastructure to emulate physical components of a network, opens an alternative to traditional network teaching. In fact, the validation process has shown that 94% of teachers and 95.8% of students consider the application to be useful, and 78% of teachers and 91.5% of students indicate that it is easy to use. Likewise, it is worth noting that the application is a great opportunity to be used in universities with limited budgets to

create and maintain physical network laboratories, as it facilitates the partitioning of physical resources and better utilizes the avail-able technological resources. Finally, it provides students with the opportunity to experiment with various real-world network scenarios, which equips them with practical skills beneficial for their development in the professional field.

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Unveiling the Supply Chain Digital Transformation of Small and Medium Enterprises

A Managerial Insight on Success Factors and Challenges

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Abstract. The global shift to a knowledge-based economy is driven by rapid advancements in information and communication technology (ICT). Within this landscape, digital transformation of supply chains is crucial for enterprises, particularly small and medium-sized businesses (SMEs), seeking to boost performance and efficiency in competitive markets. Despite increased awareness of this importance, there is lack of research from managers' perspectives on digital transformation in supply chains. The research addresses this gap by exploring managers' perceptions, identifying success factors and challenges in digital transformation within Iranian food SMEs. Through qualitative research among Iranian food SME managers, data were collected via individual interviews and document reviews, then analyzed thematically. Five key themes emerged and were discussed using the Technology-Organization-Environment (TOE) framework. The findings show that managers view digital transformation as a tool to streamline supply chain activities and enhance overall efficiency. Success factors include ICT infrastructure development and increased awareness of ICT benefits. Challenges include inadequate investment and adherence to traditional business models. Successful digital transformation requires adept ICT adoption across technological, organizational, and environmental contexts. This research contributes to the informatics research field by focusing on digital supply chain transformation, offering valuable insights for supply chain managers and SME leaders undergoing digital transformation. The research outcome offers support to practitioners in understanding their firm's digitalization progress, identifying success factors, and navigating challenges in the digital transformation journey.

Keywords: Small-Medium Enterprises (SMEs) · Digital Transformation · Business Model · Supply Chain · Supply Chain Management · Digital Supply Chain · Technology-Organization-Environment (TOE) Framework

1 Introduction

The momentum towards a knowledge-based economy, driven by advancements in ICT and digital technologies, instigates rapid transformations across diverse markets and enterprises. Small and medium-sized enterprises (SMEs), being no exception, must

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proactively embrace the changes arising from ICT to compete effectively in emerging markets. This imperative calls for their seamless transition into the era of digital transformation.

Digital Transformation (DT), a multidisciplinary concept, entails the adoption and reliance of business operations, including the business model and supply chain, on ICT and digital technologies to perform business activities and meet market requirements [34, 35, 11, 19]. It aligns with Business Model Innovation (BMI), reflecting how organizations respond to changes in competition. DT is perceived as the process through which a firm seeks to achieve BMI [34, 35, 10, 11, 19, 23], involving the exploration of ways to change the business model and implementing those changes. Additionally, DT is considered an organizational change facilitated by the application of digital technologies [2, 19], transforming organizational properties, such as the value proposition and value creation [35]. In parallel, BMI involves nontrivial changes to the properties of a business model, including the value proposition, value creation, and value appropriation [8, 15, 23]. The connection between DT and BMI is further underscored by the shared application of digital technologies [35].

SMEs are defined diversely across countries based on various criteria. In Iran, for instance, the Iranian Small Industries and Industrial Parks Organization define SMEs as firms with 5 to 50 employees [13]. The country hosts 171,000 registered SMEs operating across various industries, contributing approximately 36% to the industry sector [13]. This encompasses the food industry, including activities such as production, distribution, management, processing, packaging, transportation, and consumption. The food industry plays a pivotal role in emerging economies, such as the Iranian economy, addressing nutrition prerequisites, including food security, safety, and public health [13]. The business model of SMEs, particularly in the food sector, differs from larger counterparts, influencing the structure of their supply chain (SC) [7]. Their food supply chain (FSC) encompasses a complex network from sourcing to customer delivery, involving farmers, traders, marketers, wholesalers, retailers, caterers, and consumers [7, 21].

Iran, with a population exceeding 85 million, strategically invests in ICT to transition towards a knowledge-based economy [26]. As Iran embraces the digital era, SMEs, including those in the food industry, must undergo digital transformation to remain competitive. SMEs, especially in the food industry, serve as the backbone of the Iranian economy by creating jobs and fostering economic growth [13, 32]. Their unique business model shapes the structure of their supply chain [28, 31]. While SMEs need an in-depth understanding of technological tools and digital transformation to leverage them optimally, supply chain managers play a crucial role in helping SMEs track their data, sales, productivity levels, and expenses, identifying areas for improvement and opportunities for growth.

Previous related research [see 34 and 35] has provided a nuanced understanding of digital transformation. Within this context, the supply chain is a critical focus, probing the profound implications of technology integration; however, there is a scarcity of studies dedicated to the digital transformation of supply chains. Previous studies have also shown the interconnection of DT with business models and digital business model innovation and their impact on organizational structures and value creation [see for example 8, 10, 23]. Other previous related studies have examined the important role of SMEs in

economy and their success factors [32, see also 3, 30]. Despite the evolving nature of DT in SMEs, to our knowledge, limited research exists in the information systems literature about the supply chain of SMEs from a managerial viewpoint. Consequently, this impedes a comprehensive understanding of the factors contributing to success and the obstacles encountered by supply chain managers during the digital transformation process. To address this gap, this research focuses on the supply chain of food industry SMEs, exploring their digital transformation within the Iranian context from managers' perspective. Considering the importance of this specific industry, we pose the following research question: *What are the success factors and challenges that managers of food SMEs in Iran experience in the process of supply chain digital transformation?*

Following this introduction, the rest of the paper is structured as follows. Section two includes a brief literature review and the theoretical framework of the research. The methodological choices of the research are described in section three. In section four, the findings are presented followed by a discussion in section five. The paper concludes with section six where the conclusions of this research are presented.

2 Theoretical Background

2.1 Main Concepts

The *business model* (BM) is widely regarded as a dynamic system of interconnected and interdependent activities within firms. It elucidates how a firm crafts, delivers, and sustains its products or services within its ecosystem [2]. Over time, the definition of BM has evolved to encompass the pivotal role of information. This expanded view redefines BM as not only a framework of activities but also as a system encompassing products, information flows, and services [2]. The integration of information into the BM transforms it into a conceptual tool, empowering managers in decision-making and guiding them through the intricacies of business processes [31]. *Business Model Innovation* (BMI) empowers organizations to rethink their current strategies and aims to foster symmetric analysis, communication, and execution across organizational units, driving efficient resource allocation and experimentation [10, 19, 35]. This dynamic process involves either refining existing BMs or uncovering novel ways to deliver value. Across various studies, it is evident that the innovative BM serves as a vital nexus between organizational structure and innovation, capitalizing on technology and its applications [8, 11, 19, 23, 35]. The process wherein a company tries to achieve business model innovation by developing new business models through leveraging digital technologies for interactions across borders is known as *digital transformation* [10, 11, 19, 34, 35].

SMEs include many industries, one of which is the food industry representing one of the largest sectors in the global economy. The global food industry faces significant challenges, with approximately one-third of annually produced food (1.3 billion tons) going to waste, two-thirds of which occur within food supply chain processes like harvesting, shipping, and storage [4, 21]. In Iran, the food SME landscape comprises approximately 12,000 active firms, producing over 32 million tons of food [31]. The *supply chain,* which refers to a linear sequence of activities involved in producing and distributing goods or services [13] including sourcing raw materials, manufacturing, transportation, warehousing, and retailing, is crucial for SMEs, especially those in the food industry,

impacting their competitiveness, efficiency, sustainability and serves as a critical enabler of their business model. Still, the resource constraints typically faced by SMEs compel them to adopt efficient business models to foster innovation [13]. Understanding the dynamics and challenges that SMEs face during digital transformation is essential for policymakers and stakeholders that are seeking to support and foster their growth.

Strategic utilization of information and communication technology (ICT) is essential to navigate these challenges. The proliferation of ICTs like broadband internet, smartphones, cloud computing, and digital innovations such as AI, blockchain, IoT, and robotics is transforming supply chain processes [20, 27]. Incorporating ICT in companies leads to digital transformation (DT), where organizations revolutionize processes and strategies by leveraging digital technologies for innovation and growth. SMEs' integration of ICT significantly shapes their supply chain configuration [25–27], influenced by adoption challenges such as awareness gaps, organizational constraints, and limited strategic ICT use [25–27]. Barriers to ICT adoption include managerial unawareness, skill deficiencies, implementation costs, and limited government support [5, 18]. Financial constraints often impede SMEs' investment in ICT, affecting market access and development opportunities. Insufficient ICT systems lead to linear communication and hinder networking [24]. These issues affect both SMEs' operational efficiency and their supply chain effectiveness. Overcoming these hurdles necessitates efforts to enhance ICT adoption, improve financial capabilities, foster networking interactions, and integrate communication systems [24]. By addressing these obstacles, SMEs in the food industry can enhance competitiveness, streamline operations, and contribute more effectively to food security, safety, and public health [24].

2.2 Technology-Organization-Environment (TOE) Framework

The research employs the Technology-Organization-Environment (TOE) framework by [33] to discuss the findings and explain the intricate interplay of technological, organizational, and environmental factors influencing the SMEs' adoption of ICT solutions within their supply chain. The Technology-Organization-Environment (TOE) framework is used to analyze the adoption and implementation of new technologies within organizations [6, 22]. It recognizes that technology adoption is influenced not only by the characteristics of the technology itself but also by organizational factors, such as the SME's structure, culture, resources, capabilities, decision-making processes, and readiness for change [6, 22, 33]. In addition, the TOE framework acknowledges the influence of external factors on technology adoption within an organization [6, 22, 33]. This includes market dynamics, competitive pressures, regulatory requirements, industry standards, and the availability of complementary resources or infrastructure.

In our research, the data were collected through interviews with individual managers, yet utilized the TOE framework to discuss our findings. This approach is justified because the TOE framework, which examines the technological, organizational, and environmental contexts, can be effectively informed by the insights and experiences of individual managers. Managers are well-positioned to provide valuable information on the broader organizational attributes as they navigate and influence these contexts in their daily roles. Their perspectives offer a nuanced understanding of how these higher-level attributes manifest in practice. By interviewing individual managers, we

were able to capture detailed, context-specific insights that are essential for a comprehensive analysis of the technological, organizational, and environmental factors defined by the TOE framework. Although the TOE framework focuses on organizational-level attributes, the viewpoints of individual managers provided critical, firsthand information that reflected the collective organizational experience. This approach ensured a robust and well-rounded examination of the TOE elements, grounded in real-world managers' experiences within the SMEs.

3 Methodology and Methods

3.1 Empirical Setting and Participants

The research was conducted in the Iranian context. The choice of context was driven by the escalating government support for digital transformation among Iranian SMEs. The implementation of the National Framework of Digital Iran, 2020–2025, promises substantial advancements, particularly for SMEs focusing on digital business. Given the country's mature technological landscape, there is a strategic window for research. Additionally, the first researcher's Iranian heritage provided connections that facilitated the completion of our research. Furthermore, the specific context allowed to address both researchers' concerns surrounding waste and perishable inventories in the food industry.

Five SMEs of the food industry agreed to participate in this research. Please note that the research started as a pilot study including five SMEs, aiming to include more in the future to conduct a longitudinal study. The participating managers from the respective SMEs were purposively selected [29] based on set criteria to assure collection of rich data. That is, the participants are managers in the supply chain that have at least 5 years of work experience in order to provide relevant insight; and they are supply chain managers that work in SMEs which were at the time of research in the process of digital transformation. The participants' gender was assumed to not affect the research outcome, however, gender balance among the research participants was attempted.

Table 1. Research Participants Overview

Pseudonym	SME	Work Experience	Gender	Interview Duration
Interviewee A (IA)	SME 1	7	F	46 min
Interviewee B (IB)	SME 2	12	M	37 min
Interviewee C (IC)	SME 3	15	M	36 min
Interviewee D (ID)	SME 4	6	F	40 min
Interviewee E (IE)	SME 5	8	M	38 min

For confidentiality reasons the interviewees' and companies' names were replaced with letters and numbers as shown in Table 1. Furthermore, the research adheres to ethical principles outlined by [12] and the ACM code of ethics [1].

3.2 Research Approach

The research adopts the qualitative approach, wherein individuals or groups attribute meaning and interpret social or human phenomena [12]. Researchers conducting qualitative research typically emphasize individuals' perceptions and delve into the intricacies of a given situation. Thus, the qualitative research approach was adopted because it allowed us to capture nuanced perspectives of individual managers regarding the phenomenon of supply chain digital transformation within small and medium-sized enterprises (SMEs) in the food industry. Individual managers' perspectives provided insights that complemented the TOE framework attributes.

3.3 Data Collection

The qualitative research entailed the following methods of collecting data: individual semi-structured interviews and organizational documents review.

Interviewing was the main method for data collection in our research. We conducted semi-structured interviews with managers, employing a predefined set of interview questions to steer the discussion. The interview script included questions related to the 'what, why, when and how' of the supply chain digital transformation of the participating SMEs. This approach facilitated a thorough exploration of the research phenomenon, enabling us to concentrate on the interviewees' experiences and solicit their perspectives and insights. Interviews with managers offered nuanced perspectives on technological, organizational, and environmental contexts, capturing detailed, context-specific insights essential for analyzing the TOE factors. With the interviewees' consent, all interviews were audio recorded and subsequently transcribed verbatim to facilitate data analysis.

Documents provided by the SMEs served as an additional means of gathering data. These organizational documents were examined to obtain a more profound insight into the present state of supply chain digital transformation and to enhance comprehension of the SMEs' characteristics and requirements, and their digital transformation efforts. The review of organizational documents belonging to the participating SMEs established a foundational understanding of these specific companies, aiding in preparation before commencing interviews for actual data collection. Reviewing organizational documents complemented the TOE framework by providing objective, verifiable data on technological, organizational, and environmental contexts. These documents, such as strategic plans and financial reports, offered comprehensive insights into policies, procedures, and historical trends. This approach enhances the validity and reliability of findings by integrating multiple data sources, ensuring a robust and holistic analysis of the SMEs' operations and environment.

3.4 Data Analysis

For our research analysis, we employed a six-phase thematic analysis method [9]. Thematic analysis involves identifying, analyzing, reporting, and interpreting repeated patterns within qualitative data. This method requires interpreting data while selecting codes and constructing themes that are pertinent to the research questions.

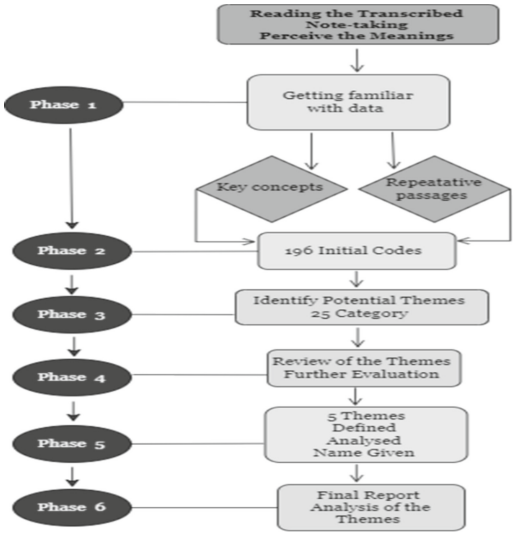

Fig. 1. Thematic Data Analysis Process followed by the authors

Thus, we familiarized ourselves with the data by immersing in the collected empirical data, primarily through reading and rereading transcribed interviews and taking notes to understand the underlying meanings as shown in Fig. 1. Initial codes were generated in the second phase, where we identified key concepts from the literature review and research question, resulting in 196 initial codes. These codes were then categorized during the secondary coding process, resulting in 25 relevant codes. In the third phase, we examined coded data extracts to identify potential themes of broader significance and further categorized codes, analyzing their relationships. Subsequently, we identified themes relevant to our research objectives. In the fourth phase, we reviewed and evaluated these themes to ensure they aligned with the research question. Based on this review, we finalized five themes representing our research findings. Finally, in the sixth phase, we reported and explained each theme, which is presented in the Empirical Findings section.

4 Empirical Findings

4.1 Theme 1: Digital Transformation Enhances Supply Chain Efficiency

Interviewees unanimously agreed that digital transformation significantly streamlines supply chain processes, describing it as 'easier,' 'faster,' 'more precise,' and 'efficient.' IA said: *"…traditionally we used to assign several employees, lots of time, cost and effort to communicate, contact and follow a project and close a purchasing contract, while all these could be done easily through a digitally integrated communication system across the stakeholders"*. IB contrasts error-prone paper plans with the reliability of digital systems minimizing costs and said: *"…our paper-based plans are prone to human error risking to impose an extra cost, time and loss of credit for the company [..]Digital*

systems instead are precise and reliable with least or no error". IE highlights tracking a shipment via mobile phone, reducing costs and effort. In summary, interviewees stressed the pivotal role of digital transformation in streamlining supply chain operations in the selected food SMEs, offering easier, faster, more precise, and efficient capabilities.

4.2 Theme 2: ICT Infrastructure Development Facilitates Digital Transformation

The SMEs during various transformation stages emphasized the impact of ICT infrastructure on supply chain digitalization. Key factors include ICT availability, skilled IT personnel, and heightened competition. IB said: *"ICT and digital technologies are readily accessible to all stakeholders in the supply chain, compelling us to accelerate digital transformation. Nowadays, suppliers, transport companies, wholesalers, retailers, and even end-users have ICT access, driving firms to leverage these technologies for delivering products and services."*

Interviewees stressed the demand for IT-skilled employees and the establishment of specialized IT departments in SMEs. IE said, *"I remember a decade before when dealing with ICT and digital technology was like a nightmare; you could rarely find one specialist in that domain. Now things have changed a lot. Recruiting IT-skilled personnel is no longer a challenge, and they are easily accessible."*

Overall, interviewees agreed that ICT infrastructure developments have facilitated digital transformation, making IT-skilled employees readily available and accelerating digital initiatives for competitiveness. The availability of ICT is seen as a driving force intensifying competition in supply chain digital transformation. Consequently, managing market changes strategically is crucial for survival in evolving markets.

4.3 Theme 3: ICT Awareness Driving Supply Chain Digital Transformation

Interviewees emphasized the critical role of heightened ICT awareness in driving digital transformation within the supply chain. They highlighted diverse perspectives on the resulting outcomes, emphasizing positive impacts on ICT adoption, implementation, and decision-making.

Sub-theme: Correlation between Awareness and ICT Adoption. Interviewees acknowledged that heightened awareness led to increased ICT adoption. IA emphasized *"As people's awareness of ICT and digital technologies increases, the adoption of such technologies becomes unchallenging and trouble-free"*. Similarly, ID emphasized the clarity of ICT advantages and the growing acceptance of ICT systems by companies, including SMEs by stating *"While the advantages of ICT are evident in every aspect of life, there is no longer a need to persuade or discuss its benefits with people. This holds for SMEs and the supply chain as well"*. According to IE the growing adoption of ICT in individuals, businesses, and society is viewed as a positive factor contributing to supply chain digital transformation.

Sub-theme: Streamlined ICT Implementation through Awareness. Interviewees recognized a streamlined connection between heightened awareness and ICT implementation. IA highlighted: *"Awareness of ICT benefits has not only accelerated ICT adoption but also streamlined implementation. It is now easier than before, thanks to the*

availability of quality software and reduced implementation time". IC linked awareness to a change in employee attitudes, fostering confidence in ICT use and reducing resistance to change and said: *"The awareness has transformed employee attitudes toward ICT, enhancing their confidence in using technology and decreasing resistance to change*". The aforementioned indicate that increased awareness of ICT benefits has fundamentally altered the way employees think and work, making the implementation of ICT easier to manage.

Sub-theme: ICT Benefits Awareness Enhances Supply Chain Decision-Making. Interviewees asserted that awareness of ICT benefits directly contributes to decision-making improvement in the digital transformation of the supply chain. IC emphasized: *"The growing complexity in the supply chain and the increasing workload we face daily can only be effectively managed through the implementation of digital transformation. This approach allows us to handle tasks more efficiently and effortlessly, enabling us to bypass errors and make precise decisions."* IB stressed the crucial role of ICT in supporting decision-making within the complex market dynamics. ID highlighted the impact of communication and data exchange on decisions. IE discussed ICT-based decision-making support for accounting and payment activities.

4.4 Theme 4: Rising Demands for ICT Investment

The interviewees emphasized a critical need for increased ICT investment among SMEs, highlighting the challenge posed by limited financial resources for such investments. They stressed the necessity to invest in three key ICT domains: acquiring and implementing technology, adapting business models, and recruiting IT-skilled personnel.

Sub-theme: Challenges in Acquiring and Implementing ICT. SMEs face financial constraints hindering investments in obtaining and implementing ICT. IB recognizes DT benefits but notes substantial financial demands for ICT acquisition and implementation, including time, software, hardware, and equipment. IC highlights an investment challenge related to industrializing packaging and traceability systems, hindered by financial barriers. He underscored the need for ICT investment by pointing out the inefficiencies of the current traditional packaging system: *"Compared to ICT-enabled systems, the current traditional packaging system is laborious, costly, and low-efficient. ICT is worth investing in, but currently, we cannot afford it."* IA and ID emphasized ICT′s importance for opening new export markets. This underscores ICT′s pivotal role in the export sector, asserting that traditional methods fall short of meeting export market expectations.

Sub-theme: Cost Considerations of ICT-Driven Business Model Changes. Interviewees addressed expenses linked to business model changes resulting from ICT implementation, acknowledging varying degrees of transformation as a cost-intensive factor. IA highlighted the multifaceted impact of digital transformation, requiring integrated changes across departments and demanding both time and financial resources. IB emphasized the transformative nature of ICT, acknowledging costs and time for implementation. ID elaborated on comprehensive alterations in stakeholder interaction, incurring additional charges for SMEs. Similarly, IE noted the financial burden of implementing changes from digital transformation, compounding costs incurred

in obtaining and implementing DT requirements. IC explored business model changes induced by the internal Enterprise Resource Planning system (ERP), emphasizing fundamental shifts in working processes and communication, with additional expenses for new software, digital equipment, devices, and hardware. He said: *"Using such a system changes the working process and communication fundamentally, so all departments should adapt to the changes. To apply the changes, we have to spend more money on new software, digital equipment, devices, and hardware."*

4.5 Theme 5: The Traditional Business Model Challenges Digital Transformation

SMEs' managers view the traditional business model as a hindrance to digital transformation. The hindrances identified include hierarchical interaction, insufficient data circulation and integration, and managerial innovation.

Sub-theme: Traditional Management. Interviewees highlighted linear and hierarchical interactions as obstacles to digital transformation. They emphasized challenges such as delays in communication due to rigid hierarchy, restricted data access, and the need to replace linear communication with networking for efficient implementation of digital transformation. IB stated: *"We should redefine the restrictions and replace linear communication with networking interaction"*. Similarly, ID commented: *"When you have linear communication while working in a complex and fast-changing environment, you cannot react proactively."*

Sub-theme: Data Fragmentation. SMEs face a hindrance to digital transformation in the supply chain due to the lack of data integration. Issues include independent departmental operations, insufficient data sharing, and challenges in distributing data across different systems. Concerns were raised about the negative impact on overall supply chain performance due to inadequate integration of HR, accounting, logistics, warehousing, and other systems. Interviewees stressed the importance of leveraging integrated data for survival, citing instances where critical data was inaccessible, leading to operational challenges. Urgency in data integration was underscored for responding to emerging markets, diverse customer demands, and stakeholder inquiries. IB said: *"In traditional supply chains, we see several different independent systems operating somewhat independently, lacking data integration."* In addition, IE stressed the urgency of integrating different systems in the supply chain, stating: *"If we fail to integrate different systems engaged in the supply chain, we are subject to lose many opportunities"*.

Sub-theme: Lack of Managerial Innovation. The absence of managerial innovation is a prevalent characteristic of the traditional SME business model, posing a challenge to digital transformation in the supply chain. Interviewees emphasized the necessity for innovative managers to reshape traditional supply chains for survival in contemporary markets. IB highlighted the vital role of innovation in adapting to dynamic markets, stating: *"Survival depends on managers sensing and responding innovatively to changes"*. IE further underscored the importance of managerial innovation in implementing digital transformation, noting: *"Traditional methods are inadequate for managing ICT-aware stakeholders and leveraging emerging opportunities."*

5 Discussion

Table 2 presents an overview of the research findings, categorizing them under success factors and challenges that managers of food SMEs in Iran experience in the process of supply chain digital transformation.

Table 2. Findings Overview

Success Factors	Challenges
ICT Infrastructure Development	Lack of ICT Investment
Enhanced ICT Benefits awareness	Cost Considerations of ICT-Driven Business Model Changes
Enhanced ICT Adoption	Traditional Business Model
Enhanced ICT Implementation	Traditional Management
Enhanced Decision-Making	Data Fragmentation
	Lack of Managerial Innovation

The research findings, focused on managers' perceptions, highlighted diverse perspectives on the current state of digital transformation in supply chains, along with associated challenges and benefits. Each SME was found to be at a unique stage of digital transformation, with varying levels of ICT adoption and readiness across digital platforms, human resources, and organizational structure. The findings showed that digital transformation is perceived to be a multifaceted concept involving various stakeholders and activities, instrumental in streamlining operations and enhancing supply chain efficiency, aligning with [24] assertions on optimizing SCM processes. Our findings emphasized the inefficiencies of traditional manual supply chain practices and stressed the urgent need for digital transformation to integrate systems and improve efficiency. The study demonstrated transformative impacts, such as streamlined communication and improved decision-making through digital systems like mobile contract monitoring and shipment tracking, leading to cost reductions and increased efficiency.

The findings highlighted the pivotal role of digital transformation in enhancing supply chain operations within food SMEs, which echoes scholars such as [27] emphasizing real-time decision-making and technological innovation deployment. The dynamic nature of supply chains was acknowledged through our findings and recognized the growing influence of ICT and the necessity to adapt accordingly, in line with [5, 7, 27] who stress embracing technological advancements for competitiveness in evolving markets. The findings also highlighted benefits such as streamlined processes, enhanced collaboration, and improved decision-making, consistent with [34, 35] and [19]. Examples from the participating SMEs demonstrated the advantages of digitalization in transportation hubs, logistics centers, and warehouses.

Regarding success factors, the findings underscored the paramount importance of ICT awareness in driving adoption, implementation, and decision-making processes. Heightened awareness facilitates smooth implementation and supports decision-making

within dynamic market dynamics, aligning with [25] and [31]. While challenges hindering digital transformation include limited investment capacity, traditional management practices, skill deficiencies, and lack of managerial innovation, echoing [5, 18, 35, 19]. Financial constraints restrict SMEs' access to ICT for competitive advantage, emphasizing the critical role of financial resources in overcoming barriers to digital transformation.

The research findings utilized the TOE framework [2, 22, 33], emphasizing the necessity of technology adoption across all levels within SMEs for successful supply chain digital transformation. Our findings advocate for comprehensive digital transformation across technological, organizational, and environmental dimensions, highlighting the importance of ICT adoption, technology integration, and improved decision-making.

Technologically, the findings emphasize the acquisition and implementation of digital technologies, exploring new possibilities. Organizationally, the findings focus on transforming managerial structures, human resources, and intra-firm communication, recommending the removal of managerial barriers, the creation of specialized IT departments, and hiring skilled employees. Establishing strong links with stakeholders, both within and outside the company, is deemed crucial, highlighting a willingness to share data. Environmentally, the findings stress the impact of competitors in dynamic markets, advocating for rapid technology adoption to survive, and recognizing the roles of ICT providers and government regulations. Table 3 illustrates how our findings advance theoretical understanding of the TOE framework in the context of supply chain digital transformation within selected food SMEs.

Table 3. Mapping Findings onto the TOE Framework

Technology Level	Organizational Level	Environment Level
Obtaining Digital Technology	Managerial Innovation	Competitors
Implementing Digital Technology	Hiring Skilled Employees	ICT Providers
ICT Adoption	Intra-firm Communication	Government Regulations

By mapping these findings onto the TOE framework, this illustration underscores the interconnectedness of technology, organization, and environment and their collective influence on the digital transformation of the supply chain.

6 Conclusion

This research paper examined the perceptions of managers regarding the success factors and challenges associated with digital transformation in the supply chain of Iranian food SMEs. The study employed interpretive qualitative methods, conducting semi-structured interviews with purposively selected managers from five Iranian SMEs and reviewing organizational documents. Thematic analysis was used to derive and interpret findings within the theoretical TOE framework.

The research findings showed that digital transformation is perceived as a key enabler for streamlining supply chain activities, leading to improved efficiency and precision in operations, with key success factors including ICT infrastructure development and increased awareness of ICT benefits. Development of ICT infrastructure is highlighted as a crucial factor that facilitates the digital transformation of supply chains, with an emphasis on the availability of skilled IT personnel. Increased awareness of the benefits of ICT has led to greater adoption and implementation of digital technologies within supply chains. Still, successful digital transformation requires ICT adoption across firm contexts based on the TOE framework. The findings also underscored the need for continuous technological updates, organizational structural changes, and environmental awareness. Concerns about political situations and global competition impact managers' confidence in pursuing digital transformation. While the research acknowledges challenges such as insufficient investment and adherence to traditional business models, it also recognizes opportunities for growth through digital transformation.

Thus, generalizations from the research results cannot be made about all SMEs; the research results can be applied to SMEs with similar context, regulations, and cultural backgrounds. Additionally, the limited sample size and specific regional focus of the study mean that the findings may not be universally applicable. Future studies could address these limitations by including a larger and more diverse sample. In addition, for future research, the study suggests exploring the impact of government support and technological development on the digital transformation of supply chains, as well as examining the role of digital transformation in reducing waste and improving inventory management in the food industry. Another theoretical framework can be applied to address the limitations of TOE framework.

This research contributes to the field of informatics by providing managerial insights into the success factors and challenges of supply chain digital transformation in SMEs. It offers practical guidance for supply chain managers and leaders planning or undergoing digital transformations.

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GHG Web Portal Dashboard: A Scalable and Flexible Digital Platform for Efficient Environmental Monitoring

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Abstract. The importance of efficient digital platforms for monitoring greenhouse gas (GHG) indicators cannot be overstated in contemporary environmental management and sustainability efforts. Such platforms are crucial for accurate, real-time data collection and integration, facilitating regulatory compliance, and enabling strategic decision-making. However, developing a usable digital platform for GHG monitoring is challenging due to the complexity of integrating diverse data sources, ensuring data accuracy and reliability, and providing user-friendly interfaces for varied stakeholders.

Despite the availability of multiple official data sources on GHG emissions, no specific digital platform exists to comprehensively aggregate and manage this data. Existing systems often lack the flexibility to incorporate new indicators and adapt to evolving regulatory requirements. This paper presents a digital platform capable of seamlessly integrating data from various sources and offering robust usability, to enhance the effectiveness of GHG emission monitoring. The platform can be valuable to stakeholders, including regulatory bodies, industry leaders, environmental organizations, and the general public to address the complexities of environmental data and advancing global sustainability efforts.

Keywords: Data Visualization · Greenhouse gas (GHG) emissions · Interactive Dashboard · Usability

1 Introduction

In recent years, the levels of Greenhouse gas (GHG) emissions into the atmosphere have become a critical indicator for metering of global warming and climate change, thus creating the need to efficiently monitor and analyze them. Efficient GHG monitoring is critical due to the increasing severity of global warming, which has led to extreme weather events, rising sea levels, and significant impacts on biodiversity and human

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health. Furthermore, international agreements like the Paris Agreement [1] and national policies mandate strict monitoring and reporting of GHG emissions to meet reduction targets and mitigate climate change impacts. This has, in fact, become imperative and a reference for environmental policies and emerging response strategies [2]. As such and considering the wide-ranging and disperse public access to relevant GHG emissions data, the existence of digital platforms that combine selected indicators to allow a more facilitated and detailed analysis for a more comprehensive understanding of emerging problems becomes essential.

Similarly, digital platforms have been shown to enhance data management in community-based monitoring, effectively supporting larger-scale environmental pattern analysis and interlinking with other platforms, although they also introduce challenges related to data control and program sustainability [3].

There are already several initiatives, platforms, and tools as United Nations Framework on Climate Change (UNFCCC) [4] whose goal is to serve as a database, but there is still a significant gap in terms of their ability to gather several data sources, or even the use of data visualization techniques to provide an easier comprehension of GHG-related indicators. However, these platforms often face significant limitations, including fragmented data sources, lack of interoperability between different datasets, and difficulty in interpreting complex data due to inadequate data visualization techniques. Additionally, the complexity of some of these platforms poses additional usability challenges in accessing data either by specific stakeholders or by general public.

Furthermore, as more and more public and disperse data sources on GHG emissions are emerging online, it becomes harder to track, gather and correlate this information.

It is in this context, we propose in this paper the CO2 Web Portal Dashboard, which focuses on the aggregation and uniformized visualization of different GHG emissions data in a single website. Improved data visualization is crucial for making complex GHG emissions data more accessible and understandable, thereby facilitating better decision-making for policymakers and increasing awareness among the general public. The platform takes advantage of a flexible software architecture, in which several types of data sources can be combined (such as the well-recognized ones in [4, 5] or [6]), as well as their associated Key Performance Indicators (KPI) and their visualization properties, such as type of graph, scales and updating times.

The platform was developed in conjunction with researchers from a university and from a company, where key user profiles were identified. Most importantly, the platform allows for the company's key users to be able to update and configure data sources with several types of integration technologies, and to setup KPI indicators without requiring programming skills. We also apply direct observation usability testing [7] and Process Mining techniques to gather and analyze user-interaction information of the platform, to further optimize its use.

The remainder of this paper is organized as follows: Sect. 2 presents the background and related work, exploring existing technologies and their limitations. Section 3 describes the research and development methodology used to create the CO2 Web Portal Dashboard. Section 4 discusses the implementation of the platform, followed by Sect. 5, which details its software features, including the recording of user interactions for further usability studies and statistics through Process Mining. Finally, Sect. 6 summarizes the

outcomes of the development and the research conducted, outlining future directions for enhancing the platform, including potential improvements and areas for further research.

2 Background and Related Work

With the constant technological evolution, various digital platforms [4, 7] have been developed to collect and process data for GHG emissions indicators, thereby addressing the growing recognition of the need for this information concerning climate dynamics to be increasingly accessible not only to researchers but also to people outside the field.

For instance, the data platform of the UNFCCC [4] provides detailed national greenhouse gas inventory data submitted by parties to the convention, facilitating transparency and tracking of their evolution towards the climate commitments.

Our World in Data [5] provides comprehensive data visualizations and research on global challenges, including climate change, to help understand long-term trends and inform policymaking.

NASA′s Climate Change website [6] provides comprehensive information on the latest climate data, research, and news. It features interactive tools, visuals, and resources to help understand the impact of climate change on our planet.

Eurostat [8] offers statistical information on various European Union policy areas, including detailed environmental data and GHG emissions metrics, to support evidence-based decision-making.

Climate Watch [9] provides accessible data on global greenhouse gas emissions, climate policies, and the progress of countries towards their climate goals, aiding in climate action planning.

The International Monetary Fund (IMF) Climate Change Indicators Dashboard [10] offers economic and financial data related to climate change, helping analyze the impact of climate policies on economic performance.

Carbon Monitor [11] offers near-real-time estimates of CO_2 emissions at global, national, and sectoral levels, providing timely insights into emission trends and policy impacts.

The World Resources Institute (WRI) [12] is a global research organization that focuses on sustainable natural resource management, climate change, energy, and urban development. WRI provides data-driven solutions and policy recommendations to promote environmental sustainability and economic opportunity worldwide.

Regarding non-regulatory research efforts, we could also find several works in the literature. In [13] the authors propose an integrative approach to reconcile city-scale GHG emission inventories with global datasets, highlighting significant regional variations and the necessity for localized emission factors to improve data accuracy.

The authors of [14] propose an advanced digital solution that combines innovative CO_2 monitoring stations and big data to deliver high-quality emission data in less than a month. This approach, initially implemented in Paris and now expanded to Italy, aims to support policy decisions and accelerate urban low-carbon transitions by providing precise and timely climate data.

In [15] the authors introduce a comprehensive system designed to monitor and manage GHG emissions in mixed farming operations. This platform aims to enhance sustainability by integrating various data sources and providing actionable insights for farmers to reduce their environmental impact.

In [16] the authors outline a strategy to help governments reduce GHG emissions through four key levers: increasing carbon sequestration, improving agricultural emission efficiency, incentivizing dietary changes, and utilizing bioenergy. This framework aims to balance environmental goals with sustainable development, ensuring food security, biodiversity preservation, poverty alleviation, and job creation.

The thesis in [17] focuses on creating a web application that integrates diverse sustainability data sources to help users visualize CO_2 emissions calculations effectively. The study, part of the WISER project, addresses challenges in calculating and tracing greenhouse gas emissions, aiming to improve transparency and reliability by connecting different data formats and sources. The implementation and findings are demonstrated, with future improvements discussed.

The work in [18] focuses on analyzing building energy efficiency in New York through the lens of environmental justice. It evaluates the distribution of Energy Star Scores and their relation to socio-economic factors, such as low-income and non-white populations. The study uses statistical methods, regression analysis, and Multi-Criteria Decision Analysis (MCDA) to assess energy efficiency and develop a Building Energy Efficiency Justice (BEEJ) index. The primary output is an interactive dashboard that visualizes this data, combining spatial and statistical information to aid decision-making for various stakeholders. The dashboard, built with HTML, CSS, JavaScript, Python, PostgreSQL, and Tableau technologies, allows users to explore energy efficiency scores and their intersection with environmental justice indicators. The full database is publicly accessible for future research purposes.

In [19], the authors describe a platform that utilizes data from sensors and IoT devices to assist farmers in optimizing resource use, reducing costs, and minimizing environmental impacts. It integrates advanced technologies such as Artificial Intelligence (AI) and big data analytics to enhance farm management and promote sustainable agricultural practices.

The authors of [20], present a novel system leveraging blockchain technology to enhance the transparency and accuracy of GHG emissions tracking. This innovative system ensures secure and tamper-proof recording, verification, and disclosure of emissions data, improving reliability and supporting informed climate policy decisions.

In [21], the authors present a 4D interactive carbon emissions dashboard designed to visualize and assess the environmental impact of urban buildings. This innovative tool integrates time-based data, offering a comprehensive view of carbon emissions and enabling detailed analysis over time. It aids in evaluating and improving building sustainability practices by providing actionable insights into emissions trends and patterns.

Despite all the above-mentioned initiatives, and to the best of our knowledge, none of these digital platforms address flexibility, scalability and usability challenges posed mainly by the growing number of data sources and correlated GHG emissions-based KPIs. Additionally, the combination of these disperse data sources brings challenges

regarding their integration within a single platform, the configuring of suitable data visualization properties, and the platform's usability considering the amount of data hierarchies and filtering options to provide. Our platform provides special attention to these challenges, by proposing a suitable software architecture and adequate usability testing, supporting detailed and dynamic data analysis across various fields.

3 Method

Throughout the development of this project and the digital platform itself, the methodology employed was characterized by a hybrid approach that effectively merged elements of rapid prototyping with Scrum principles [22, 23]. This approach ensured a dynamic and flexible development process. Regular meetings were conducted, where the partner team provided various prototypes that served as visual and functional blueprints for the platform′s expected capabilities. These prototypes detailed necessary data functionalities and the user interface, setting clear expectations and goals for each development cycle.

Each prototype underwent rigorous evaluation and refinement, incorporating extensive adjustments, enhancements, and the introduction of new features. This iterative process was crucial for the progressive evolution and continuous improvement of the platform, ensuring that each version advanced closer to the final vision. By iteratively refining the prototypes, the team could enhance usability and functionality, addressing emerging challenges and user feedback promptly.

To support the development process, we predominantly utilized the Jira platform for its robust project management capabilities. Jira′s backlog feature and timeline tools were instrumental in managing the project′s scope and scheduling. Establishing a comprehensive task registry and defining the duration and dependencies of each task allowed the team to plan and execute the project effectively within the allocated timelines. This structured approach facilitated clear communication and coordination among team members, ensuring that all tasks were aligned with the project's overall objectives.

For usability testing, we developed user-interaction tracking features that enabled Process Mining of navigating data provided by beta testers. These features recorded all user interactions with the platform, offering valuable insights into user behavior and platform performance. The auxiliary testing component supported this process, providing a robust framework for analyzing and improving user experience. This method of collecting and analyzing user interaction data was vital for identifying usability issues and making data-driven improvements to the platform.

4 CO_2 Web Portal Dashboard Development

The implementation of the project commenced with data regarding the country of Portugal, aiming to consolidate diverse data on specific Portuguese indicators into a single platform. Key users of this platform included researchers, general public and, most importantly, a company partner team responsible for updating and configuring GHG emissions data in the platform, without requiring programming skills.

4.1 Software Architecture

Aiming for the scalability and flexibility requirements of the platform, as well as the ability for key users to update its datasets and configure KPI visualizations, we propose in Fig. 1 the CO2 Web Portal Dashboard software architecture, using the C4 model[1] nomenclature.

The architecture is divided into several interconnected components that handle different aspects of the application, from user management to data visualization and administration.

The architecture serves two main types of users: the general public and administrators. The general public users access the system through a frontend web application. This application is built using Vue 3, a progressive JavaScript framework known for its efficiency and flexible structure. The frontend provides a user-interface, allowing users to visualize CO2 data through various interactive elements. Users can filter and select data based on specific parameters such as geographical regions or specific time frames. The ability to choose data from maps enhances the interactivity, providing a spatial understanding of the data. Users of type administrators have a different interaction with the system. They utilize the same frontend interface but are provided with additional software features to update and manage data sources and KPIs. This role is crucial for maintaining the accuracy and relevance of the data presented to the general public users.

The core of the application′s functionality lies within the API and Backend Application, which is developed using Laravel 10. Laravel′s robust features and Model-View-Controller architecture allows for the handling of complex business logic and data management. The backend is responsible for all server-side logic, including data import, processing, and API management. It communicates with the frontend via JSON over HTTP, facilitating a seamless data flow that supports the application's dynamic features.

Data persistence is managed by a MySQL database, which stores all essential data such as user information, environmental indicators, and filters. MySQL was chosen for its reliability, performance, and widespread support. The database schema is designed to efficiently store and query large sets of environmental data, optimizing both retrieval and update operations.

An important element of this architectural design is the incorporation of Grafana[2] an open-source platform dedicated to monitoring and observability. In this case, Grafana is employed to allow administrators the power of configuring KPI visualizations that general public users will access to. Therefore, administrators can access their Grafana portal through a simple account and configure several KPI panels and data sources directly. These Grafana embedded panels are then incorporated into the frontend web application, providing general public users with advanced data visualization tools that include graphs, charts, and maps.

Overall, the architecture is designed with a focus on scalability and flexibility. By separating concerns among the frontend, backend, and database components, the system ensures that each component can evolve independently while maintaining overall system integrity. The use of containerization for both the Vue 3 frontend and Laravel 10 backend

[1] https://c4model.com.

[2] https://grafana.com.

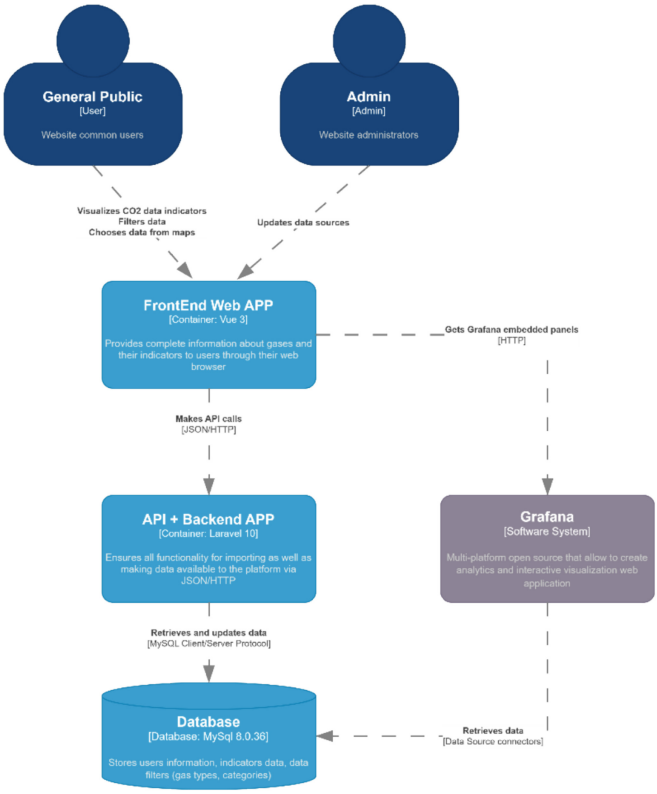

Fig. 1. Platform architecture.

enhances the portability and scalability of the application, facilitating easy deployment and scaling across different environments.

4.2 Implementation

Regarding the development of the platform, it started with the integration of technologies such as Grafana, Vue, and Laravel. The first prototype confirmed the feasibility of embedding Grafana charts directly into Vue, enabling basic interactions with the panels through URLs that transmitted variables for MySQL queries, and enabling access control to the panels by associating them with a specific organization.

Following the positive evaluation of the initial prototype, the project progressed to a second stage, where the user interface was significantly enhanced. The homepage visible at Fig. 2 was redesigned to categorize indicators, simplifying navigation and access to detailed information without the need for multiple clicks.

This restructuring provided a more fluid and intuitive user experience, enhancing efficiency in data visualization. To improve interaction with the platform, further enhancements were needed, constantly incorporating direct feedback from the company partner team. Consequently, a fixed sidebar was introduced, providing immediate access to recent

aggregated data, and allowing users to view essential statistics without interrupting the main navigation. Additionally, the establishment of a development infrastructure on the Azure platform facilitated continuous access to project progress, utilizing a reverse proxy [24] architecture with Grafana to ensure security and efficiency.

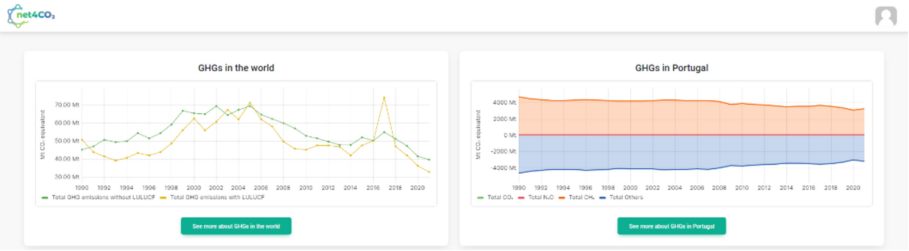

Fig. 2. Platform homepage.

Development then advanced to the next stage, which expanded data import functionalities to accommodate various sources and formats. Specific routines were created to handle complex data from different categories, such as emissions by gas type and sector, utilizing external libraries to assist in data importation and filtering. This version prepared the platform to support data from multiple national and international contexts, enhancing its adaptability and applicability. Subsequently, based on user feedback, improvements were primarily focused on refining the data import window, reorganizing it to enhance user interaction and optimize the import process visible (Fig. 3). The interface was also modified to improve filters and facilitate direct selection of categories or sectors, depending on the data being imported. Additionally, data was separated and reorganized into sections to enable better navigation and location of data required by users with the help of a top navigation bar.

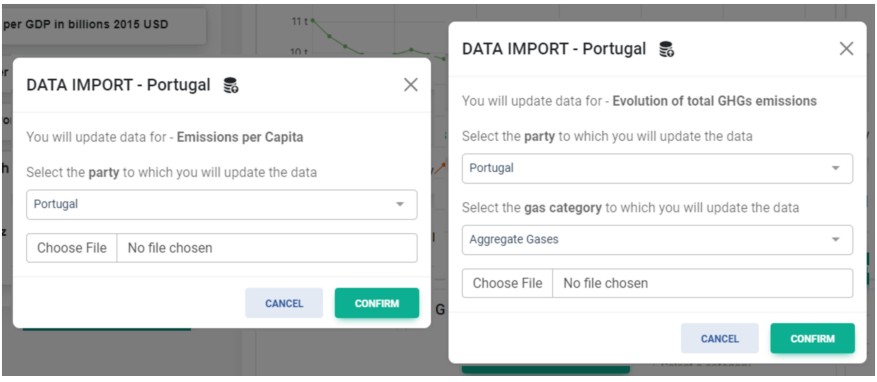

Fig. 3. Import windows.

To enhance the platform and the regional indicator, a map facilitating the manipulation and visualization of geographic data was also developed. Due to the limitations of

existing tools for integrating interactive maps, the adopted solution was to use a combination of bar charts in Grafana and vector maps (SVG) directly in Vue for more effective manipulation. This configuration allowed the region selected on a bar chart to automatically change the map visualization, thus improving user interaction with regional data. The regions on the map were colored according to the volume of gases emitted, with variations based on the selected year, which helped the visual interpretation of environmental data on a regional scale. This approach not only overcame the technical challenges of integration but also provided a more dynamic and informative tool for geographic data analysis on the platform visible at Fig. 4.

With this extensive implementation framework and following the testing phase, the development proceeded to create global (world) indicators, which essentially followed the same structure while only changing their data sources. Here, we were able to introduce real-time data fetching by using the NASA API [6]. This implementation also required the "export to image" feature of the charts, so that produced indicators could be exported and used in other data visualization scenarios.

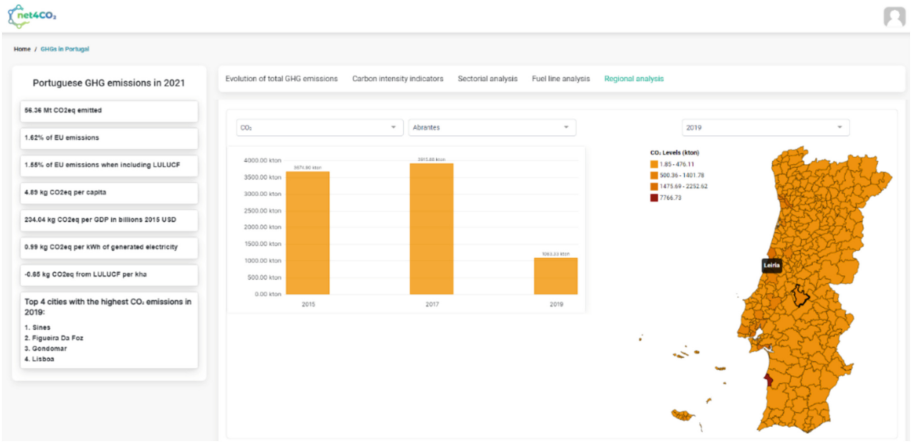

Fig. 4. Geographic data analysis.

5 Usability Testing

5.1 User-Interaction Tracking

The user-interaction component has been implemented primarily based on the recording of user gestures in the frontend web application. The component enables the generation of comprehensive event logs that detail all user activities within the platform, containing the user-interaction activity performed (e.g. *click on button A*), the actual origin place in navigation (e.g., *homepage*), timestamps and, most importantly, an identifier for the feature being performed (e.g., *feature 23: visualizing GHGs for an industry sector of a country*).

This component is designed to be toggled on and off as needed (Fig. 5), serving as a wizard that guides users during testing phases. It provides explicit instructions on the tasks to be performed, marks the start and end timestamps for each task, and measures the total time spent on all testing activities. This extensive data collection is instrumental in conducting further process mining thorough analyses aimed at understanding and improving platform usability bottlenecks and deviations to a normal user interaction. The statistics produced are then crucial for identifying usability trends and pinpointing specific areas where the platform can be optimized to enhance user experience and operational efficiency.

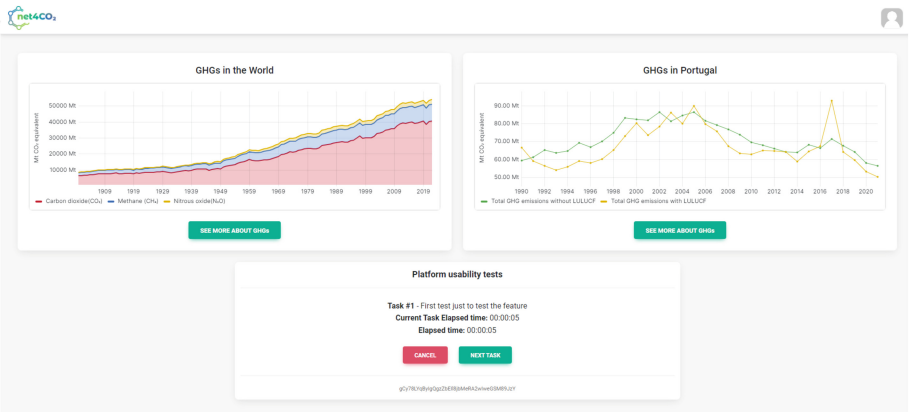

Fig. 5. Wizard tests.

5.2 Direct Observation Tests

Following the completion of the initial version of the platform, with all indicators pertaining to Portugal implemented, direct observation tests were conducted, followed by the deployment of a Post-Study System Usability Questionnaire (PSSUQ) involving several volunteers, using the process mining data, and the wizard tool to conduct the tests.

The direct observation tests entailed users with different capabilities as visible in Table 1, performing a variety of tasks, covering as many application software features as possible. Tasks included identifying specific amounts of GHG emissions by area and by Portugal's gross domestic product, as well as specific emission data for certain years and locations, such as N_2O *emissions in Leiria district in 2017*. Additionally, users were instructed to execute standard operational procedures on the platform, such as logging in and out, and importing data for specific indicators, such as the overall evolution of GHGs for the transportation sector in Portugal. These tasks not only tested the user's ability to navigate and interpret data but also assessed the efficiency of the data import processes and interaction with various interfaces and panels on the platform.

These tasks Table 2 were meticulously planned, and the test results included metrics such as successful task completion, time taken for each task, number of incorrect clicks,

Table 1. Tests users' information.

	Age	Gender	Professional Area
User 1	26	Female	Chemical Engineering
User 2	34	Male	Economies and Environmental Management
User 3	25	Male	Chemical Engineering
User 4	28	Male	Chemical Engineering
User 5	38	Female	CO2 Utilization Team Leader
User 6	27	Female	Chemical Engineering
User 7	52	Female	Scientific Research
User 8	26	Male	Environmental Engineering

and whether users followed the expected path without deviation. The analysis of these parameters revealed that, despite a somewhat slow start in adapting to the platform, the time required to complete tasks tended to decrease as users became more familiar with the application environment, visible at Fig. 6, except for task 6, where user 5 took a considerably long time to complete the task, and user 3 in task 7, both of whom can be considered outliers.

Table 2. User Tasks.

Task	Description
1	Identify the amount of emissions per area for Portugal in 2014
2	Specify the amount of CO2 emissions including LULUCF for Portugal in 2019
3	Specify the amount of N2O emissions in Leiria for 2017
4	Using the main indicators, specifically the left sidebar, indicate the amount of emissions per GDP (Gross Domestic Product) in Portugal for the most recent available year
5	Log in to the platform
6	Import data for the Total GHGs (Greenhouse Gases) evolution in Portugal, and then for the European Union
7	Import data for the transportation sector in Portugal
8	Import data for CH4 (methane) emissions in Portugal
9	Log out of the platform

However, it was identified that the data import window required restructuring, especially because tasks related to this functionality showed prolonged completion times and a significant rate of incorrect clicks, suggesting that the integration and arrangement of elements on the interface could be optimized for easier use. Furthermore, the current structuring of the indicators was considered confusing by some users, implying the need for a different organization that facilitates access to information. The data import tasks

particularly revealed that different import windows presented distinct challenges, with some facilitating interaction more than others.

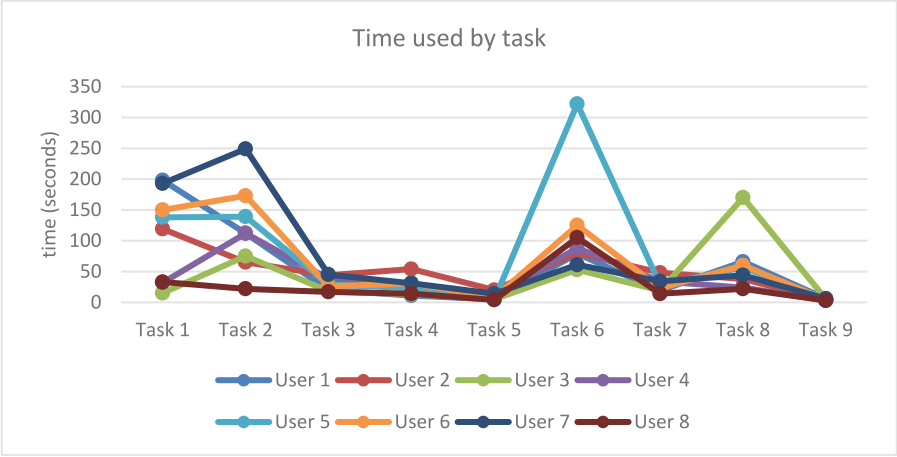

Fig. 6. Time used by task in seconds.

Regarding following the expected path, most users did not experience significant difficulties, except in initial tasks while they were still adapting to the platform. The challenge of importing data for the European Union was a particular obstacle, highlighting the need for a more intuitive and uniform import window.

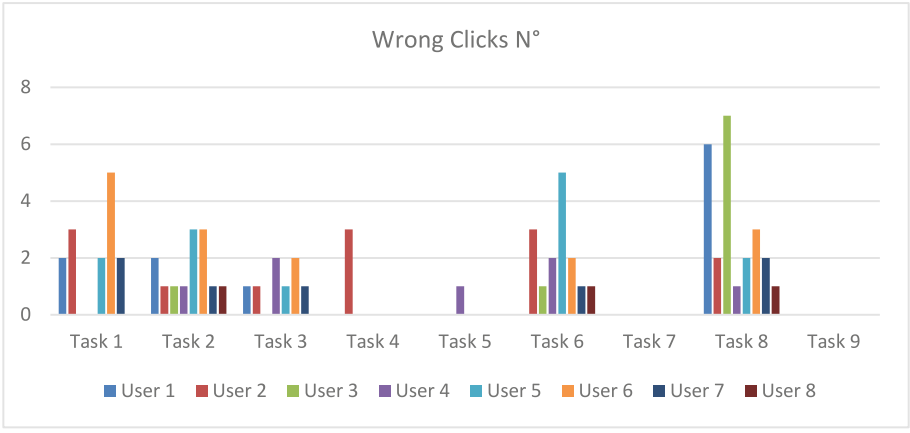

Fig. 7. User's wrong clicks by tasks.

Regarding the number of incorrect clicks, visible in Fig. 7, practically all tasks have them. As mentioned earlier, this is due to users initially getting accustomed to the interface, misreading certain panels, and interacting with incorrect panels. This highlights

the need to structure the platform differently so that a new user can achieve their reading objectives more quickly.

Furthermore, we observe that tasks 6 and 8, related to data importation, are the only ones with incorrect clicks, contrasting with task 7, which had no incorrect clicks. In task 6, the incorrect clicks were due to users having difficulty switching the import between the current party and the European Union, indicating a need for modification and the creation of a homogeneous import window. As for task 8, the number of incorrect clicks was primarily because the filters for the gas to be imported were outside the import window instead of within it, once again necessitating a change to make this window homogeneous.

Subsequently, users were given the opportunity to explore the platform freely, which allowed for the collection of additional feedback through the PSSUQ. Despite some positive comments, suggestions for improvement again indicated the need for a revision of the element layout on the interface, particularly the import window, whose filter placement outside the main window unnecessarily complicated interactions. These insights emphasize the importance of a clear and well-structured interface in optimizing user experience and suggest a thorough review of the platform layout to reduce visual clutter and facilitate access to desired information. The proposed restructuring aims to significantly enhance the usability and efficiency of the platform.

6 Conclusion and Future Work

The development of the CO2 Web Portal Dashboard as a scalable and flexible monitoring digital platform represents a significant contribution advancement in the visualization and management of environmental data and provides a comprehensive dashboard for tracking GHGs emissions. Utilizing cutting-edge technologies such as Grafana, Vue, Laravel and MySQL, the platform has been crafted to provide dynamic, real-time access to GHG data. This approach has not only streamlined the data visualization process but also enhanced accessibility and interactivity for the general public, experts and regulators, enabling more informed discussions and decisions on environmental issues.

The platform's architecture allows for the integration of disperse data sources, and for the configuration of KPIs by non-programmers, ensuring it maintains updated and useful through time. It also provides efficient handling of large datasets and complex user interactions. By integrating advanced visualization tools through Grafana, the application offers diverse data visualizations, which are essential for effective environmental monitoring and advocacy.

The broader implications of this research include potential impacts on policymaking, industry applications, and global sustainability efforts. By offering a reliable and accessible tool for GHG emissions tracking, the platform can support policymakers in developing informed strategies to meet international climate targets. Industries can leverage the platform to monitor and reduce their carbon footprints, contributing to broader sustainability goals.

Looking ahead, a near-future analysis will include the automatic collection of user-interaction data and the application of additional Process Mining techniques to further enhance the usability of the platform.

It is also foreseen the integration of predictive analytics using Machine Learning techniques that will transform the platform from a descriptive to a prescriptive tool, providing forecasts and actionable insights that could help preempt environmental issues.

In summary, the CO2 Web Portal Dashboard not only addresses current challenges in GHG emissions tracking but also lays the foundation for future innovations in environmental data management, contributing to global efforts in combating climate change.

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The Sensors and Their Communication Among the Production Activity of Agroindustry Ecosystems

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Abstract. The agroindustry sector, and the product production activity in particular, plays an important role in modern economies and population feeding. Digital transformation is happening in almost all areas and this industry is also its object of interest. Despite the adoption of digital technologies in the agroindustry not being new, it is important to reflect in how it can be improved.

It is aim of this research to explore and describe a variety of sensors used in the production activity of agroindustry context and for those sensors what kinds of communication systems are available for Internet of Things and the outlining their current challenges. This research is intended to support a further development of a technological framework for intelligent precision agroindustry production.

The use of sensorization and communication networks in agroindustry product production and animal husbandry offers several advantages such as driving efficiency, sustainability and productivity. Although some aspects are yet to be addressed to make those contributions more effective.

Keywords: Agroindustry sector · Communication systems · IoT and Sensors

1 Introduction

Population growth is creating an additional need for food products, putting pressure on the agribusiness sector. It is estimated that the global need, in terms of food, will increase by around 60% by 2050. Covering a wide range of activities from agriculture, animal production, forestry and fisheries, the agribusiness sector, like many other areas, needs decision-making based on reliable data collected in the field and stored in databases. Information collection begins in the production site and the devices normally associated with this data collection are sensors that act as endpoints or nodes interconnected in a network, usually the Internet. These devices emit a flow of information that is supposed to be transmitted securely, in a format that allows it to be stored for later analysis [1].

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The great advantage of these IoT devices is their ability to collect and send data for analysis in real time or stored locally and transferred later to storage systems. However, for an architect, farmer or researcher it is critical to understand the data as well as how the data can be interpreted. Besides understanding what data is collected and how it is acquired, in a massive IoT deployment, it is useful to know what can be sensed, and what the constraints are for various sensors. Most connected devices will be sensors, so it is important to understand their role [1–7].

The aim of this study is to perform an exploratory and descriptive research to identify a variety of sensors used in the production activity of agroindustry context and for those sensors identifying the available communication systems for IoT and the outlining of its future challenges.

This identification will be of great importance to look for existing standards for data collection, transmission and storage to be able to build a technological framework for intelligent precision agroindustry production.

This document is organized in eight sections: the current, introduction, methodological approach, followed by a section describing the sensors, sensor communication systems, how data can be transmitted to the cloud, case studies of using the technology presented in this document, discussion, outlining of the open challenges and ends with the conclusion.

2 Methodological Approach

To identify the sensors used at agroindustry production sector and their communication systems and protocols, a narrative literature search was performed at the bibliographic sources IEEEXplorer, ScienceDirect and ACM Digital Library using the terms 'Agoindustry AND production AND sensor', 'Agoindustry AND production AND sensor communication systems', 'Agoindustry AND production AND sensor network' and 'Agoindustry AND production AND sensor communication protocols'. Only were considered publication with less than 10 years and written in English language and with specific application at the agroindustry production area.

3 Sensors for Production Activity of Agroindustry Sector

Sensors play a vital role in capturing valuable data after a set time difference. The cloud services store this extensive set of data produced by these sensor devices to manage its storage. Agricultural scientists, farmers, and researchers then use this collected data for research and analysis to improve agriculture-related activities in different scenarios. Farmers can access real-time crop information with IoT sensors, which help them make better decisions. A better understanding of the forecasted parameters enables farmers to plan and manage cultivational activities, yield, and storage. Agroindustry sensors to enhance crop yield are required to reach the maximal efficiency of agroindustry production [1–7].

The sensors applied to goods production and animal husbandry included in this overview are soil moisture, temperature, pH and light.

3.1 Soil Moisture Sensors

Connected sensors transmitting data can provide better insight into the soil water content. Nutrient leaching can be reduced by efficiently managing irrigation systems, water, and energy. These sensors are essential for modern agriculture, as they allow precise irrigation management, saving water and improving crop productivity [8–10]. Types of this sensor characterization are presented at Table 1.

Table 1. Soil moisture sensor types characterization [8–10].

Type	Function	Operation mode	Advantages	Disadvantages
Resistance Sensor	Measure the electrical resistance between two electrodes inserted into the soil	When the soil is moist, the resistance between the electrodes decreases, allowing greater flow of electrical current. When the soil is dry, resistance increases, reducing current flow. The sensor translates resistance changes into a soil moisture value	Simple, easy to install; Relatively cheap; Allow real-time monitoring; Adapted to various types of soils; Integration with IoT; Durability	Lower precision in soils with high salinity; Regular maintenance due to corrosion of electrodes; Need for calibration; Environmental and mechanical interference
Capacitance Sensor	Measure the soil's ability to store an electrical charge, which varies with the water content in the soil	Two metal plates (capacitor) are inserted into the ground. Water in the soil changes the dielectric constant around the plates, changing the capacitance. The sensor monitors changes in capacitance and converts the data into a soil moisture value	Greater precision; Lower maintenance requirements compared to resistive sensors; Less affected by soil salinity; Speed in reading; Integration with IoT	Purchase cost; Complexity in calibration; Subject to interference from temperature variations and accumulation of dirt; Limitations of use in some types of soil

(*continued*)

Table 1. (*continued*)

Type	Function	Operation mode	Advantages	Disadvantages
Tensiometry Sensors	Measure the tension or suction force that plant roots have to exert to extract water from the soil	It is a water-filled tube with a porous ceramic tip. When inserted into the ground, the water inside the tube attempts to balance the moisture in the surrounding soil. A pressure gauge in the pipe records the tension, which is inversely proportional to the water content in the soil	Measure water availability for plants and are widely used in agricultural research; Application on different types of soil; Durability; Simple maintenance; Integration with other systems	High cost; Sensitivity to physical damage; Installation complexity; Need for calibration; Sensitivity to environmental conditions; Limitation on measuring depth
Time Domain Reflectometry Sensors	Measure soil moisture	Measure soil moisture based on the reflection of an electromagnetic pulse sent through a probe	Very accurate; Can be used in various soil conditions; Less sensitive to temperature variations; Low maintenance; Integration with other systems	More expensive; Installation complexity; Need for calibration; Sensitivity to temperature variations; Dependence on electrical energy for its operation; More complex data interpretation
Frequency Domain Reflectometry (FDR) Sensors	Similar to TDR, but uses variations in the frequency of an electromagnetic signal to measure soil moisture	A variable frequency signal is sent through a probe in the ground. Changes in the frequency of the return signal are used to determine the dielectric constant of the soil, which is related to its water content	High precision; Less sensitive to the electrical properties of the soil (e.g. salinity); Low maintenance	Cost; Installation complexity; Need for calibration; Vulnerability to mechanical damage; Dependence on electrical energy for its operation; More complex data interpretation

3.2 Temperature Sensors

Temperature sensors are essential for monitoring thermal conditions, which directly influence plant germination, growth and health. They are also used in animal production environments to monitor and control the climate, ensuring that animals are kept in a comfortable and healthy environment. Proper temperature control is crucial for animal

Table 2. Temperature sensor types characterization [10–14].

Type	Function	Operation mode	Advantages	Disadvantages
Thermocouples	Measurement at various soil depths, useful in detailed thermal profile studies	Based on the Seebeck effect, where two different metals generate an electrical voltage proportional to the temperature difference between the junctions	Accurate; Low cost; Temperature measurement at various depths of the soil, useful in detailed thermal profile studies; Robustness and durability	Accuracy limited at low temperatures; Sensitivity to electromagnetic interference; Need for calibration; Influence of extreme environmental conditions
Thermistors	Semiconductor devices that have an electrical resistance that varies predictably with temperature. The resistance of the thermistor decreases when the temperature increases (NTC thermistor - Negative Temperature Coefficient) or the resistance increases when the temperature increases (PTC thermistor - Positive Temperature Coefficient)	When a thermistor is exposed to a change in ambient temperature its electrical resistance changes according to its NTC or PTC characteristic. The change in resistance is measured electronically by a readout circuit connected to the thermistor Based on the measured resistance, an interface circuit converts the information into a corresponding temperature value	They offer high precision in temperature measurement, especially in smaller temperature ranges; Low cost; Robustness; Low energy consumption	Accuracy limited at low temperatures; Sensitivity to environmental variables; Need for calibration; The linearity of the data, due to temperature, may be compromised; Sensitive to mechanical damage and corrosive substances

(*continued*)

Table 2. (*continued*)

Type	Function	Operation mode	Advantages	Disadvantages
RTDs (Resistive Temperature Devices)	Use the variation in the electrical resistance of a metal (usually platinum) with temperature	The RTD electrical resistance increases linearly with increasing temperature (positive temperature coefficient)	Accuracy; Wide temperature range; Robustness; Immunity to electromagnetic interference; Integration with other systems	Cost; Sensitivity to mechanical damage; Energy consumption; Need for calibration; Affected by corrosion and contamination
Infrared sensors	Measure infrared radiation emitted by the ground, converting it into a temperature reading	All bodies with a temperature above absolute zero emit infrared radiation (IR). IR sensors use a special sensor that can detect this IR radiation emitted by objects and surfaces	Do not require direct contact with the ground, allowing quick and non-invasive measurements; Remote measurement; Real-time operation; Integration with other systems	Cost; Sensitive to environmental conditions; Reflection; Need for calibration; Susceptible to electromagnetic interference
Temperature Data Loggers	Record temperature data over time, often combined with various types of temperature sensors	Continuous and long-term monitoring of soil thermal conditions at different locations and depths	Continuous monitoring; Can generate automatic alerts; Can store large amounts of data for later analysis	High cost; Complex configuration; Need for calibration Battery life; Limited storage capacity
Wireless temperature sensors	Use wireless technology to transmit real-time temperature data to a control center	Remote and real-time monitoring of soil conditions, ideal for precision agriculture systems and large area management	Simple installation and maintenance; Wide coverage; Integration with IoT and management systems; Real-time monitoring	High cost; Battery life; Signal interference; Data security; Dependence on Network Infrastructure; Need for calibration

(*continued*)

Table 2. (*continued*)

Type	Function	Operation mode	Advantages	Disadvantages
Environment temperature	They measure both the humidity and the temperature of the environment, providing essential data to maintain the thermal comfort of the animals	Used to monitor air temperature in breeding facilities. They can be simple sensors, such as digital thermometers, or more complex ones, such as sensors connected to automation and environmental control systems	Accuracy; Continuous monitoring; Integration with automated systems; Sending alarms and notifications; Resistance	Cost; Need for calibration; Sensitivity to environmental conditions; Electromagnetic interference; Energy dependence
Body temperature	Rectal thermometers – measure the internal temperature of animals; Subcutaneous sensors - Inserted under the animals' skin, they allow continuous monitoring of body temperature; Ear sensors - Devices attached to the animal's ear and measure body temperature through the ear's blood vessels	These could be Thermistors; Thermocouples or infrared sensors. The latter detect the infrared radiation emitted by the animal's body, converting it into a temperature reading	Animal health monitoring; Continuous monitoring and automation; Integration with other management systems	Cost; Interference with animal behavior; Limitations in network connectivity; Limited useful life; Need for calibration

welfare, production efficiency, and disease prevention [10–13]. The Table 2 presents the temperature sensors characterization.

3.3 PH Sensors

The soil pH sensor is a device that allows you to accurately monitor the acidity or alkalinity of the soil, which is a critical factor for crop growth, and analyze whether the necessary nutrients exist and based on this information, guide farmers to make the correct decisions in applying the nutrients necessary for crops to develop [10, 15, 16]. The Table 3 shows the characterization of the pH sensors.

Table 3. pH sensor types characterization [10, 15, 16].

Type	Function	Operation mode	Advantages	Disadvantages
Soil	Portable pH Sensors: Hand tools that can be inserted directly into the soil to measure pH at different points in the field pH Sensors Integrated into Soil Monitoring Systems: Fixed or mobile devices that are integrated into monitoring systems, often combined with humidity, temperature and nutrient sensors	They operate based on a pH-sensitive glass electrode. The electrodes measure the concentration of hydrogen ions (H^+) in the soil When the sensor is inserted into the soil, the interaction between the electrode and hydrogen ions generates an electrical potential proportional to the concentration of H^+. This potential is converted into a pH value	Real-time monitoring; IoT compatibility;	Cost; Need for calibration; Sensitivity to extreme environmental factors; Limited useful life
Water	Portable: Used to measure the pH of irrigation water, reservoirs, lakes and rivers Submersible: Designed to be submerged in water. Used to monitor reservoirs and automated irrigation systems	the pH sensors are strategically distributed across multiple zones. Each sensor covers a specific area; The sensors are connected to a central monitoring system; Monitoring can be continuous or with real-time analysis	Real-time monitoring; IoT compatibility;	Cost; Need for calibration; Sensitivity to extreme environmental factors; Limited useful life; Limited coverage area; Electromagnetic interference

(*continued*)

Table 3. (*continued*)

Type	Function	Operation mode	Advantages	Disadvantages
Wireless and IoT	Wireless to Ground: remote and real-time monitoring. Integrated into wireless sensor networks that transmit data to a central platform Wireless for Water: Similar to wireless ground sensors but designed to operate in aquatic environments	Wireless pH sensors are installed in different locations, in the soil or in the irrigation system. There can be several sensors to cover different growing zones The sensors send data via the wireless network to a central monitoring system for access via computer or mobile device Monitoring can be continuous or in real time	Real-time monitoring; Access to remote information; Integration with management platforms; Scalability	Cost; Dependence on network infrastructure; Interference from other devices; Energy dependence; Need for calibration; Data security

3.4 Light Sensors

Crops need abundant sunlight for their development. Different groups of plants react differently to light intensity, so some groups need greater intensity while other groups need lower intensity. Light sensors allow the collection of data on light intensity and based on its analysis, help in decision-making to maximize efficiency in the use of resources necessary for sustainable crop growth [10, 17–20]. The Table 4 shows the characterization of the light sensors.

4 Sensor's Communication Systems

Most sensors used in the context of agroindustry management use analogue or digital communication methods and nowadays digital communication prevails with the use of analogue-digital converters (ADC) allowing data processing by microcontrollers or data acquisition systems [21].

Digital communication can be carried out via RS-232/RS-485 serial interfaces for communication between the sensor and the computer, controller or other devices. The communication protocols used can be I2C/SPI (Inter-Integrated Circuit/Serial Peripheral Interface) for proximity, Modbus for industrial environments with connection to Modbus RTU or TCP/IP networks, allowing integration with Supervisory Control and Data

Table 4. Light sensor types characterization [10, 17–20].

Type	Function	Operation mode	Advantages	Disadvantages
Photometers	Measure light intensity in units. Used to determine the amount of light available in each area or agricultural environment. Useful for checking the amount of light that plants receive and can be used to adjust lighting in greenhouses or other environments	Sensors are installed at different points to monitor light intensity throughout the day The sensors are connected to a central system that controls the artificial lighting and irrigation system During cloudy days, sensors detect low light and activate artificial lighting to complement natural light The data can also be used to adjust irrigation, ensuring that plants receive the correct amount of water based on data analysis	Accuracy; Continuous and real-time monitoring; Easy to operate	Cost; Sensitivity to adverse environmental conditions; Need for calibration; Dependence on natural lighting; Limitations in closed environments; Electromagnetic interference
Photosensors	Sensors that detect the presence of light. Used in automated lighting systems to activate or deactivate lights based on ambient brightness Used to control artificial lighting in greenhouses or indoor growing environments	Sensors are installed in different areas of the crop field to measure the intensity of sunlight They are connected to a central monitoring system with access via computer or mobile device Data on light intensity is sent continuously to the central system or monitoring can be in real time, identifying variations in light intensity throughout the day and in different parts of the field	Precision; Energy saving; Integration with automation systems; Adapted to environmental variations	Interference from ambient light; Need for calibration; Cost; Limitations in closed environments; Integration with other systems

(*continued*)

Table 4. (*continued*)

Type	Function	Operation mode	Advantages	Disadvantages
Spectroradiometers	Advanced sensors that measure the spectral distribution of light falling on a given area, provide detailed information about the spectral composition of light, including intensities of different wavelength ranges The measurements are useful for understanding how different wavelengths affect plant growth and development	The sensors are installed in different areas and at different heights, including at leaf level in the canopy Spectroradiometers are connected to a central monitoring system that collects and analyzes spectral light data Data collection and analysis can be continuous on the intensity and spectrum of sunlight throughout the day and in different parts of the crop The central system analyzes spectral data to understand the distribution of different bands of light (UV, visible, infrared) that plants receive	Ability to carry out detailed and precise measurements of the spectrum and distribution of light incident on agricultural crops; Continuous and real-time monitoring	Sensitivity to adverse climate variations; Need for calibration; Cost; Limitations in closed environments
Radiometers	Measure electromagnetic radiation in different wavelength ranges, including visible light and sunlight. Used to quantify the solar radiation available in a specific area and can be important for optimizing the positioning of outdoor crops or calculating the amount of light energy available for photosynthesis	Sensors are installed in strategic locations within the field to measure incident solar radiation. They are placed at different heights to capture the radiation that directly reaches the plant leaves Monitoring can be continued by measuring incident solar radiation at different wavelengths throughout the day Data is collected at regular intervals and sent to a central monitoring system	Precise measurement of solar radiation; Continuous and real-time monitoring	Sensitivity to adverse climate variations; Need for calibration; Cost; Limitations in closed environments

Systems Acquisition (SCADA) and the SDI-12 (Serial Data Interface) used in environmental sensors, suitable for long distances and allowing communication between multiple sensors [21, 22].

In wireless communications, the low-power Zigbee protocols stand out, ideal for field sensors, given their low energy consumption. They can send data to a Zigbee hub or gateway, which relays the data to centralized monitoring systems [21].

LoRa (Long Range) technology allows long-range wireless communication, with low consumption, being ideal for rural environments and communicates with LoRaWAN gateways, transmitting data to local networks or the internet [10, 21].

The Wi-Fi technology used in modern soil moisture sensors allows data transmission directly to local networks and, via the internet, to cloud services. Bluetooth technology is used for short-range communications. The sensors can be connected to smartphones, tablets or computers, to allow quick configurations and/or data transfers [22]. The main characteristics of these sensorial communication systems can be seen in Table 5.

Table 5. Sensor's wireless communication system characterization [10, 21, 22].

Type	Normal range	Throughput	Power Consumption	Topology	Cost
Wi-Fi	10–100 m	Up to 700 Mbps	Medium	Star, Mesh	High
Bluetooth/BLE	50–100 m	100 Kbps – 2Mbps	Low	P2P, Star, Mesh	Low
LoRaWAN	2–15 km	10–50 Kbps	Low	Star	Low
Zigbee	10–100 m	20–250 Kbps	Low	Mesh	Medium
Satcom	Up to thousands km	Up to 100 Gbps	Very high	P2P, Mesh	High

5 Data Communication Systems for the Cloud

Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP) are lightweight communication protocols for IoT that are used to send data to MQTT servers or brokers in the cloud, facilitating integration with monitoring and analysis systems. Some sensors can send data directly to web servers via HTTP or HTTPS protocols, facilitating integration with web-based platforms. Many modern sensors have dedicated mobile apps that connect via Bluetooth or Wi-Fi allowing you to view data and perform calibration and diagnostic procedures directly from mobile devices. Some implemented solutions use Mesh networks, where each sensor acts as a node that can retransmit data from other sensors, increasing the coverage area and reliability of the network. In remote areas, sensors can use Satcom (Satellite Communication) since wireless networks are unavailable or not feasible to implement [21, 22]. The main characteristics of data communication systems for the cloud can be seen in Table 6.

Table 6. Data communication system for the cloud characterization [10, 21, 22].

Type	Normal range	Throughput	Power Consumption	Topology	Cost
Modbus	Up to 1.2 km over RS-485	Up to 1.2 Kbps over RS-232 Up to 10 Mbps over TCP/IP	Medium	Bus, Star	High
MQTT	Undefined, depends on the network	It depends on the network. designed to operate on networks with limited bandwidth. Up to 100 m (Wi-Fi) or 15 km (Cell phone)	Low	MQTT Broker	Low

6 Case Studies Implementing Sensorial Technology

In Napa Valley, California (USA), vineyard managers have implemented smart irrigation systems to optimize water usage in grape production. Soil moisture sensors are strategically placed throughout the vineyards to monitor soil water levels in real time. These sensors are integrated with weather stations that track local climatic conditions, including temperature, humidity, and solar radiation [23]. The data was acquired using soil moisture and temperature sensors spread through the production area and communicating data to the aggregation point using LoRaWAN technology. This implementation allowed water conservation through applying water only when necessary (the vineyards have reduced water usage by up to 30%), improved grape quality resulting from well managed water supply (this is critical for wine production) and the reduction in water usage has also translated into significant cost savings for the vineyard operators.

Cotton farmers in Gujarat, India, have implemented IoT-based pest monitoring systems to detect and manage pest infestations. Pheromone traps equipped with sensors capture data on pest populations, while environmental sensors monitor conditions that influence pest behavior, such as temperature and humidity [24]. The data was acquired using soil moisture, pH, light and temperature sensors spread through the production area and communicating data to the aggregation point using Bluetooth/BLE technology. This implementation resulted in early pest detection, through identifying early warnings of potential pest outbreaks, allowing for timely intervention; reduced pesticide usage (pesticide application is based on sensor data has reduced overall pesticide use by 30%, lowering costs and minimizing environmental impact); and improved crop quality, by controlling pests more effectively, the quality of the cotton crop has improved, leading to better economical return.

7 Discussion

Sensors can be powered by batteries, solar panels, or directly from the electrical grid, depending on the infrastructure and specific needs of the system. Most of them can process data locally or send it for external processing, depending on the type and design of the sensor and the system in which it is integrated [10, 22].

Some smart sensors are equipped with microcontrollers or microprocessors that allow local processing of data. These sensors can perform everything from basic calculations to the use of more complex algorithms to interpret the data. Local processing can reduce the amount of data to be transmitted, saving network bandwidth. They provide faster information for immediate actions, such as possible need for adjustments in the operation (Ex: irrigation systems). Local processing is a type of processing independent of ongoing connection to external systems, useful in areas with limited connectivity. Application examples include sensors that automatically adjust irrigation based on soil moisture readings and sensors that only send alerts when critical conditions are detected [10, 21, 22].

Many types of sensors are designed to transmit raw data or with some processing to a centralized system for subsequent analysis, through wireless communication systems (Wi-Fi, LoRa, Zigbee) or through wired infrastructures (RS-485, Modbus). The data is sent to servers or cloud platforms where it is processed using advanced machine learning and big data algorithms. Data from multiple sensors can be aggregated and analyzed together, providing a more comprehensive view of the problem [10, 21, 22].

The choice for local or centralized processing depends on the complexity of the processing tasks. Simple tasks such as humidity and temperature measurements and basic alerts can be performed locally. Complex tasks, such as forecasting water needs and integrating with meteorological data, often require external processing. The most advanced sensors with integrated microcontrollers can process data locally. Simpler sensors can only collect and transmit data. Sending data for centralized (external) processing is viable and beneficial if it is in areas where there is an infrastructure with good connectivity. In remote areas, local processing may be more practical. Applications that require immediate actions (e.g. automated irrigation, increasing/decreasing light intensity), local processing may be preferable. Many current systems combine both approaches to maximize the advantages of each [21, 22].

The sensors presented in this analysis constitute only a small part of a larger, more comprehensive set, but which are aimed at the future work that is proposed to be developed.

8 Open Challenges

Climate change along with population growth are influencing the ways in which our food is grown and these can be changed through the introduction of IoT and sensors in the agro-industrial sector. With the use of these technologies, farmers can collect and evaluate data in real time on a set of environmental variables that affect crops (temperature, soil moisture, pH, light) and make the most appropriate decisions about where, how, when and how to sow, irrigate, fertilize and harvest. Based on reliable data,

with appropriate collection and analysis tools, it will be possible to increase production, efficiency, significantly reduce waste and harmful environmental effects. The use of sensors as a fundamental element in data collection also presents a set of challenges and needs [10].

Increase precision in the data collection operation and reduce the need for calibration depending on soil conditions and the detail of the variables being measured. Soil conductivity and salinity can interfere or negatively influence measurements [22].

The durability, reliability and frequency of maintenance actions on components since, for the most part, they operate in adverse environments, exposed to climate changes, high levels of humidity and corrosive agents. The need to reduce the energy consumption required for its operation, which is intended to be increasingly residual, moving towards energy self-sufficiency [22].

Develop and/or improve communication standards and protocols to facilitate data exchange and interoperability between devices/systems and ensure that data communication is carried out securely. It is necessary to ensure privacy and security of data collected by sensors by implementing robust security measures and ensuring compliance with data protection regulations. Reduction in development and manufacturing costs for sensors and their components, as well as maintenance and integration costs with other systems [10, 21, 22].

Increase data storage, processing and analysis capacity and the development of analysis tools in line with the needs of those involved in the decision-making process. Incorporate nanotechnology to allow greater sensitivity, precision and reduction of costs and dimensions, as well as better integration with IoT systems [11].

Develop research and development of multiparametric sensors that allow the simultaneous measurement of several parameters, with greater precision and integrated into data communication systems and big data platforms with advanced analyzes and modeling. Adhere to national and international quality and safety standards and regulations and develop/improve standards for the manufacture, operation and integration of sensors in agroindustry management activities with the aim of standardizing practices promoting sustainable and efficient agricultural practices. Train those involved in the process, mainly farmers and agribusiness professionals, to effectively use sensors and related technology [10, 21, 22].

9 Conclusion

The use of sensorization and communication networks in agroindustry product production and animal husbandry offers several advantages such as driving efficiency, sustainability and productivity. Despite the initial investment being the major barrier, lack of trained personal and better understanding of the technology and how the information is analyzed and presented are still challenges to overcome.

Further research required for improving the sensorial transformation of agroindustry production, examples are: developing algorithms and frameworks that can integrate data from multiple sensor types (e.g., soil, climate, plant health, and livestock) to provide a holistic view of the agricultural environment; exploring the deployment of Internet of Things (IoT) devices with edge computing capabilities in remote and large-scale agricultural settings; investigating the miniaturization of sensors and the development of

energy-harvesting technologies to power them, especially in harsh or remote environments; developing new types of sensors capable of detecting a broader range of biological and environmental parameters, such as plant nutrient levels, animal biomarkers, and micro-climate variations; development of advanced biometric sensors for livestock that can monitor more detailed health parameters, such as blood glucose, respiratory rates, and hormone levels, of animals in real time; focusing on the integration of environmental sensors to monitor the impact of agricultural practices on ecosystems, such as soil degradation, water quality, and biodiversity; and promoting standards for data acquisition and transmission standards for better integration with analysis systems.

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Representation Dimension of Quantitative Reasoning and Cooperative Learning

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Abstract. The aim of this study was to establish the correlation between cooperative learning and the representational dimension of quantitative reasoning in university students. The study is based on a quantitative research approach, a correlational level and a non-experimental cross-sectional design. The sample consisted of 121 students from a private university in Lima. To evaluate cooperative learning, a questionnaire composed of 29 questions was used. On the other hand, to evaluate the representation dimension of quantitative reasoning, an evaluation was carried out through a real context situation using a rubric. The results indicated a significance level of 0.000, which led to the conclusion that there is a significant relationship between cooperative learning and the representation dimension of quantitative reasoning.

Keywords: Learning · cooperative learning · quantitative reasoning · representation

1 Introduction

University education is constantly undergoing changes and adaptations that seek to respond to the learning needs that students demand, especially in the field of mathematical reasoning. The pandemic has forced to rethink methodologies and strategies to be implemented. In this context, the implementation of active methodologies becomes a priority need that leads to the development of autonomous and reflective learning. According to [1], students see interaction as positive, since it prepares them for teamwork and allows them to develop intra- and interpersonal intelligence, as well as to express their points of view, give and receive criticism, coexist with differences and reflect on the point of view of others, since group discussion contributes to the understanding of the subject from different perspectives; that is, it teaches them to live together.

Cooperative learning is an active methodology that develops learning through interaction and teamwork. In this sense, [2] mentions that it implies cooperation between

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peers, in whose interaction shared learning is generated. For [3], cooperation generates interaction activities that promote the search for the achievement of the other, that is, mutual benefits in a context in which the reward is shared. In this line, for [4], members study and collaborate as a group to reach the goal set for learning and problem solving. In this way, cooperative learning contributes to student socialization. On the other hand, in relation to academic achievement, evidenced in the grades, for [5] there is a considerable increase in the grades obtained in the evaluations and in the team application activities, and these exceed those obtained individually, which could be due to the interaction that teamwork implies. Likewise, their research affirms that, as a result of the learning developed in teams, individual grades increased.

For the development of this research, cooperative learning has been dimensioned in five elements: positive interdependence, promoting interaction, individual and group responsibility, learning of social skills, and review of the group process. Positive interdependence is achieved when common and interdependent goals are set. Likewise, promoting interaction implies that each member of the group should give and receive support from others, constructively managing conflicts and developing efficient communication. On the other hand, individual and group responsibility implies that each member assumes responsibility for the achievement of learning, considering that what is learned in a group, each student can also do later on individually. Cooperative learning contributes to the development of social skills necessary to ensure the proper functioning of the team, among these can be mentioned respect, communication, conflict resolution, among others. Finally, the review of the group process is the reflection that the team makes on its work, determining the beneficial actions of its members and those that should be improved. [6].

One of the types of cooperative learning is TAI (Team Assisted Individualization, TAI). According to [7], this method consists of students working in heterogeneous teams, with one of them being the most "capable" and who will be the guide for their peers who are less advanced in the topics or activities to be developed. This contributes to the motivation of the team to help each other achieve the objectives set. Likewise, the teacher plays a mediating role, which facilitates the creation of a favorable learning environment for the student. The dynamics proposed during data collection consisted of organizing small groups that work through various learning units. Each group is responsible for ensuring that all members understand the content, using techniques such as peer teaching, mutual support and collaborative review of exercises. In addition, each group member is responsible for explaining and helping to resolve questions, which promotes effective collaboration and deep learning.

Regarding mathematical reasoning, this is defined as the fundamental capacity in mathematical learning to establish conjectures and generalizations, as well as the investigation of why and to develop and evaluate arguments. In this context, conjecture implies inferring a narrative that has a possibility of theorization, generalization implies the identification of a pattern that allows the extension of the inference to a broader scope than the matter that originated it, and the argumentative justification of a statement or a mathematical fact implies the investigation of why [8]. Along the same lines, "quantitative mathematical reasoning" refers to the application of fundamental mathematical skills,

such as the interpretation and critical analysis of quantitative information from reality to reach relevant conclusions or find solutions to problems in real situations [9].

Likewise, in relation to quantitative reasoning, five dimensions are identified as being developed by the researchers of this article: interpretation, representation, calculation, analysis and argumentation of contextualized problems; the main subject for this research being the representation dimension of quantitative reasoning. In this regard, [10] found that different representational notations, such as graphs and matrices, can significantly influence learners' interactions and subsequent use of knowledge. This is particularly important in the development of conceptual knowledge and mathematical thinking, as demonstrated by [11]. The use of computer-based representation tools can further support collaborative learning, as suggested by [12]. Finally, [13] highlights the role of cooperative learning in the development of cognitive skills, essential for effective quantitative reasoning. Thus, this research seeks to identify the relationship between cooperative learning and the representation of contextualized problems in mathematics students.

2 Methodology

The study was conducted using a non-experimental cross-sectional design, as defined by [14]. This approach allows the phenomena to be observed in their natural state without the intervention of the researcher, thus eliminating the manipulation of variables. This approach is optimal when the main objective of the research is not the direct resolution of the problem.

Regarding the correlational level of the study, it is consistent with the perspective of [15], who argues that correlational research is indispensable for determining and quantifying the strength of association between variables. This is indicative of the objective of the study to quantify the extent of the relationship between variables, in addition to recognizing it.

The fundamental nature of the research is in line with the concepts of [16], who postulates that basic research extends the boundaries of existing knowledge without pursuing immediate practical applications. The aim of this research is to improve the theoretical understanding of quantitative reasoning and cooperative learning in the student environment.

Finally, the quantitative methodology employed in the research, consistent with the sentiment articulated by [17], allows emphasizing the importance of numerically presenting the results to facilitate their objective interpretation. The use of descriptive and inferential statistics by these authors allows a precise and transparent understanding of the relationships and trends among the variables investigated.

In the academic year 2023-01, 176 students of both sexes enrolled in the mathematics course at a private university in Lima, Peru, constituted the study population (Table 1).

The stratified probability sampling technique with proportional allocation was used to obtain a sample that was representative of the population. This methodology ensures that each sector of the population is duly represented in the sample, showing the diversity and fundamental attributes of the group of students (Table 2).

For the collection of information in this study, a questionnaire composed of 29 questions was used, which was based on the Cooperative Learning Application Scale (CLAS)

Table 1. Population

SCHOOL YEAR	COD. COURSE	SECTION	CODING	QUANTITY
202301	MA435	AR0E	202301-MA435-AR0E	40
202301	MA435	AR1I	202301-MA435-AR1I	40
202301	MA435	AR1B	202301-MA435-AR1B	40
201801	MA435	VA1A	202301-MA435-VA1A	39
202301	MA435	VA0E	202301-MA435-VA0E	17
TOTAL				176

Table 2. Sample

CODING	N	%	n	%
202301-MA435-AR0E	40	23%	28	23%
202301-MA435-AR1I	40	23%	28	23%
202301-MA435-AR1B	40	23%	28	23%
202301-MA435-VA1A	39	22%	26	21%
202301-MA435-VA0E	17	10%	11	9%
TOTAL	176	100%	121	100%

of the University of Deusto, according to reference [18]. This questionnaire was created with the purpose of analyzing cooperative learning and its different aspects: social skills and strategies, individual responsibility, face-to-face interaction, positive interdependence and evaluation. Responses were categorized on a five-point scale, ranging from "Strongly disagree" to "Strongly agree".

In addition, a real contextual situation was used to assess quantitative reasoning. This assessment was carried out using a three-part rubric, classifying responses into levels of insufficient, in process, and sufficient. Five dimensions were considered: Interpretation, Representation, Calculation, Analysis and Argumentation (Table 3).

The authenticity of the instruments used in this research was confirmed by the critical evaluation of two specialists in the field and an expert in research methodology. In addition, the reliability of the instrument was validated by calculating Cronbach's alpha coefficient. Values of 0.899 and 0.865 were obtained for the cooperative learning and quantitative reasoning argumentation variables, respectively. These results indicate high reliability in both cases.

Data analysis was performed using SPSS Statistics version 29 software. Descriptive statistical techniques were used for qualitative variables, mainly for the purpose of generating graphs that represent the information visually. In order to carry out hypothesis testing, inferential statistical methods were used, such as normality tests like the

Table 3. Dimension representation of quantitative reasoning

	Insufficient	In process	Sufficient
Representation Dimension: "Ability to convert relevant information into various mathematical forms (e.g., equations, graphs, charts, tables, words)."	Graphically represents the mathematical object that relates to the real context situation	Identifies a mathematical and/or statistical expression but does not relate to the problem situation	Identify a mathematical and/or statistical expression related to the problem situation in a real context

Kolmogorov-Smirnov test and Spearman's Rho correlation coefficient, since the data did not present a normal distribution.

Throughout the process, the confidentiality of the participants was strictly respected. Likewise, the required authorizations were obtained both from the persons involved and from the relevant educational institution.

The proposed assumption suggests that there is a significant relationship between the ability to represent quantitative reasoning and the cooperative learning process, establishing a direct connection between both research variables.

3 Discussion and Results

3.1 Cooperative Learning Variable

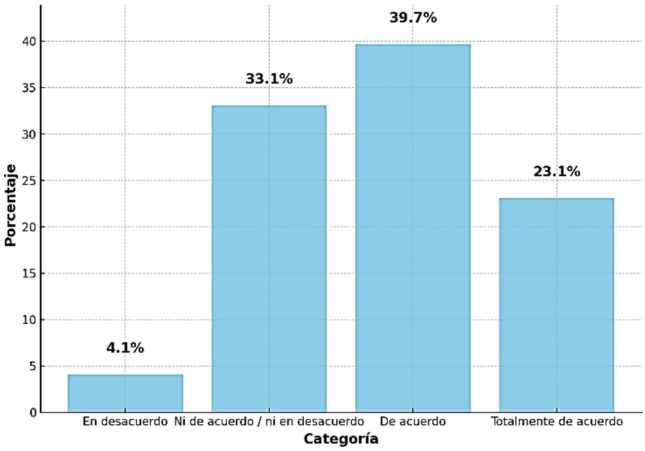

Fig. 1. Cooperative learning

According to Fig. 1 of the study, in relation to the application of educational strategies that facilitate the achievement of the group's objectives through team and collaborative work, 39.7% of the participants expressed their agreement. On the other hand, 4.1% of the respondents expressed complete disagreement with these educational strategies. These data show the different perceptions of the respondents regarding the use of cooperative learning strategies.

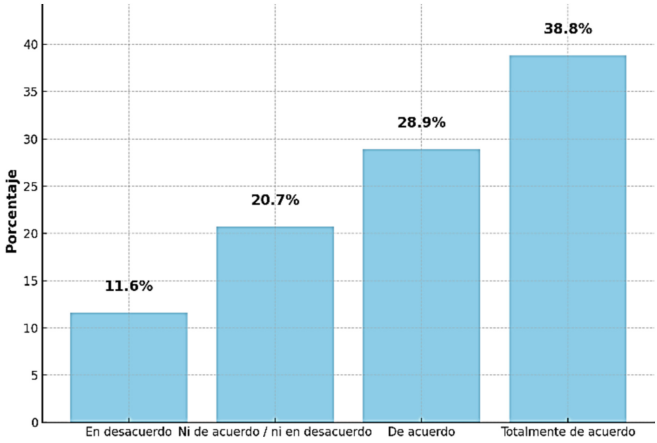

Fig. 2. Positive interdependence

According to Fig. 2, in relation to the educational strategies employed to achieve the group's shared objectives, 67.7% of the participants stated that they completely agreed or agreed. Regarding the role assumed within the team, recognizing that the success of the group depends on the individual success of each member, 11.6% of the respondent's expressed disagreement with the educational strategies mentioned.

In Fig. 3, in relation to constructive and close interaction in the work group as a didactic strategy to improve results, 71% of the students surveyed expressed complete agreement or agreement. They argued that by collaborating, the results were more favorable by being able to discuss the assigned tasks compared to individual work. On the other hand, 2.5% of the respondents indicated that they strongly disagreed with this strategy.

In Fig. 4, in relation to the implementation of promotional and positive dynamics in the groups as an educational strategy, 65.2% of the students surveyed expressed complete agreement or agreement with this strategy, since it implies a deeper commitment of each team member in carrying out the planned activities. On the other hand, 5% of the respondents indicated that they totally disagreed with this strategy.

In Fig. 5, in relation to the use of strategies that promote the development of socioemotional skills in the teams, 71.9% of the students surveyed expressed their total agreement and agreement with this practice, since it facilitates that each member can relate more fluently with their teammates. On the other hand, 2.5% disagreed with this strategy.

In Fig. 6, in relation to the educational strategies implemented through the monitoring and evaluation of the groups, 49.6% of the respondents indicated that they had no clear

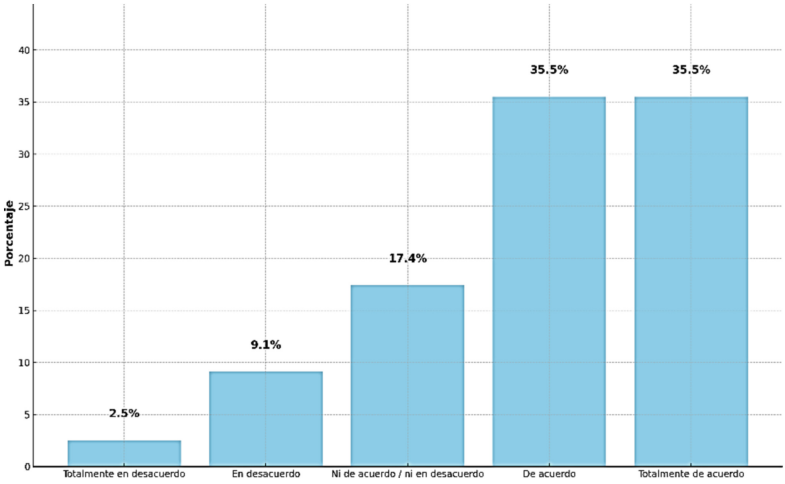

Fig. 3. Face-to-face interaction

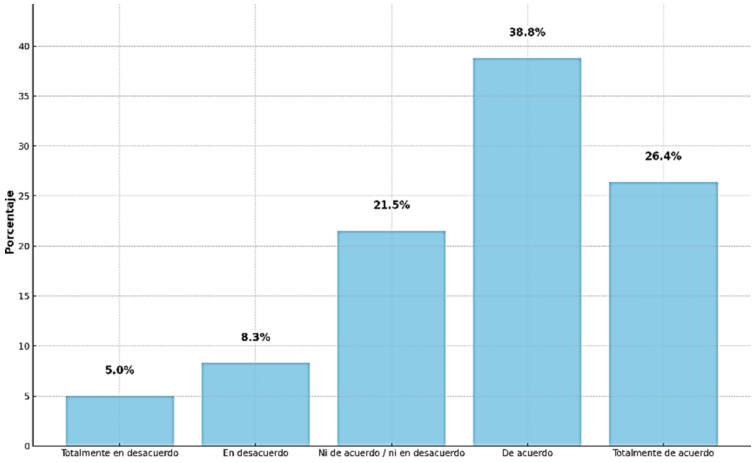

Fig. 4. Individual responsibility

opinion on the matter, while 15.7% expressed their agreement with these strategies, considering that they facilitate and encourage the members to acquire a participatory, multidimensional and integral character by evaluating the performance of each group member.

3.2 Quantitative Reasoning Variable

According to Fig. 7, more than half of the students analyzed failed to reach the adequate level (52.9%). This indicates a lack in the development of skills to interpret, represent, calculate, analyze and argue contextualized problems. On the other hand, only 47.1% of

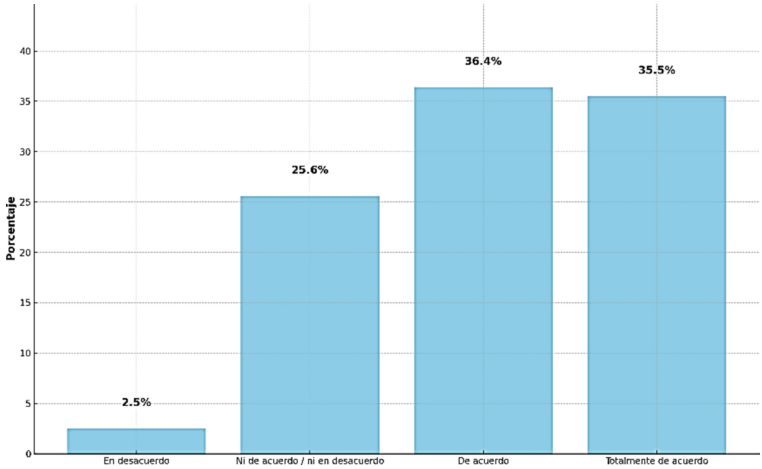

Fig. 5. Social skills

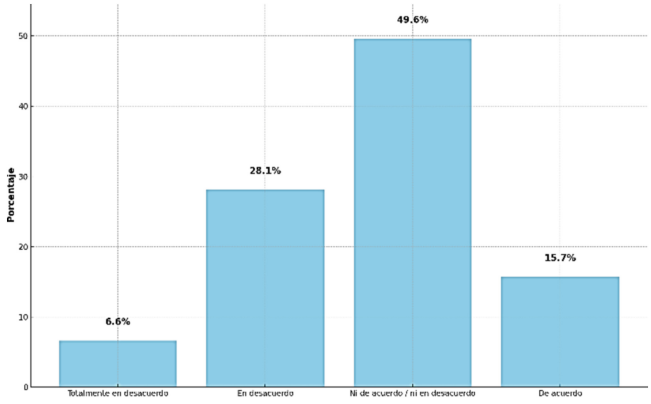

Fig. 6. Group evaluation

the students managed to reach the adequate level, which indicates the need to introduce new strategies that promote the development of quantitative reasoning.

According to Fig. 8, the majority of university mathematics students (59.5%) demonstrate adequate ability in the representation dimension of quantitative reasoning, while 37.2% are in the process of reaching this level. Only 3.3% present insufficient skills. These results suggest that, although the majority have satisfactory skills, it is necessary to provide additional support to those who are in the process and to the minority with significant difficulties.

3.3 Correlation Between Quantitative Reasoning and Cooperative Learning

The researcher's assertion is validated, since the significance level is less than 0.05, which indicates a relevant correlation between collaborative teaching and quantitative

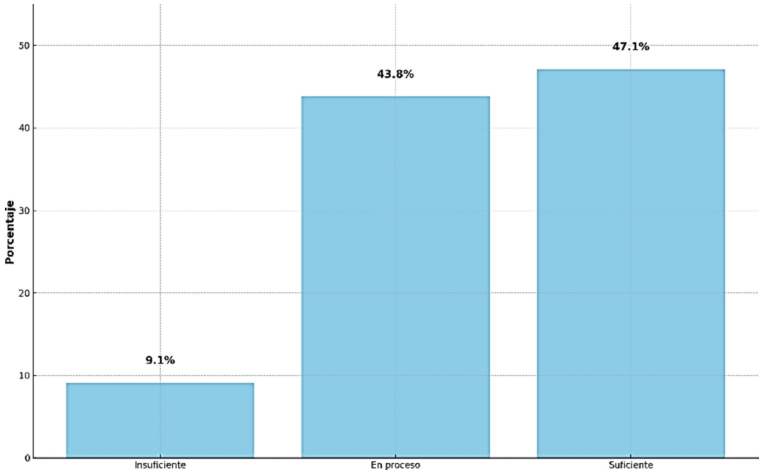

Fig. 7. Quantitative reasoning

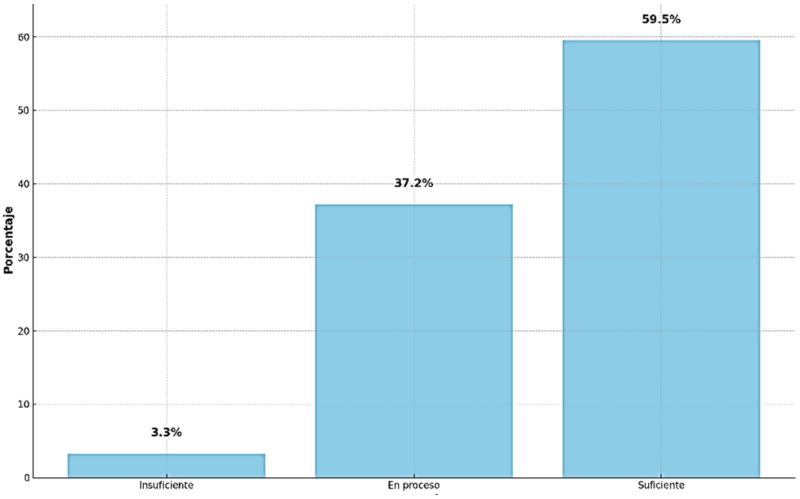

Fig. 8. Representation dimension of quantitative reasoning

Table 4. Quantitative reasoning and cooperative learning

		Quantitative reasoning
Cooperative learning	Spearman's correlation coefficient	0.808
	Sig. (bilateral)	0.000
	N	121

thinking in first cycle mathematics students of a private university institution in Lima. Spearman's Rho correlation coefficient of 0.808 supports this observation, indicating a significant positive correlation between both variables (Table 4).

3.4 Correlation Between the Representational Dimension of Quantitative Reasoning and Cooperative Learning

Table 5. Dimension representation of quantitative reasoning and cooperative learning

		Quantitative reasoning
Representation	Spearman's correlation coefficient	0.566
	Sig. (bilateral)	0.000
	N	121

A significance value below 0.05 confirms the researcher's hypothesis about the relationship between the variables, demonstrating their significance. In addition, Spearman's Rho correlation coefficient of 0.566 shows a moderate positive correlation between these variables. This suggests that cooperative learning has a significant influence on representational ability in mathematical contexts. The analyses performed show disparities in the results achieved in the area of instruction and collaborative learning in university education, particularly in the areas of mathematics and science (Table 5).

When analyzing the antecedents, differences are observed in the results obtained regarding the relationship between cooperative learning and the development of cognitive and quantitative skills. The antecedents can be grouped according to the correlation and influence found high correlation, moderate correlation, and no significant correlation. For example, [10] found that external representations in a collaborative context significantly influence knowledge construction and interaction among students, highlighting the usefulness of representational tools in collaborative learning. Likewise, [13] evidenced that cooperative learning facilitates the development of cognitive skills, highlighting the importance of interaction and teamwork for the achievement of educational objectives.

On the other hand, studies such as [11] identified a moderate influence of mathematical representations on quantitative reasoning, suggesting that symbolic and diagrammatic representations can improve conceptual understanding in mathematics. However, [12] found no significant differences in student performance when using different representational tools, despite recognizing the importance of representations in collaborative learning.

The observed differences may be related to several factors. Sample size is one of the key elements, as studies with larger samples tend to show stronger correlations due to greater data diversity and reduced sampling error. For example, the study by [10] used a larger sample, which could explain the high correlation observed. In addition, the nature of the data collection instrument has a significant influence; studies using

graphical representation tools, such as diagrams and concept maps, tend to show higher correlation due to the explicit visualization of relationships and concepts.

Data collection methodology also plays a crucial role. Qualitative approaches, such as the one used by [13], allow for a deeper understanding of students' interactions and perceptions, revealing more subtle and significant influences of cooperative learning. Likewise, studies with a focus on collaborative interaction and group discussion, such as those by Suthers and colleagues, tend to find a higher correlation due to the importance of discourse and negotiation in collaborative learning.

The results obtained in this study confirm a high correlation between cooperative learning and quantitative reasoning in undergraduate mathematics students at a private university in Lima, with a Spearman correlation coefficient of 0.808 and a significance of 0.000, indicating a high and significant positive relationship. In addition, a moderate correlation was found between the representation dimension of quantitative reasoning and cooperative learning, with a correlation coefficient of 0.566 and a significance of 0.000.

These findings align with the results of [10], who found a high correlation between representational tools and collaborative learning, as well as with the results of [13], who highlighted the effectiveness of cooperative learning in the development of cognitive skills. However, the results show a stronger correlation compared to the moderate findings of [11], which could be due to differences in the educational context and methodologies used.

The significance value ($p < 0.05$) in the results allows confirming the researcher's hypothesis about the existing relationship between cooperative learning and quantitative reasoning, as well as between the representation of quantitative reasoning and cooperative learning. Spearman's Rho correlation coefficient of 0.808 indicates a high positive correlation, suggesting that it is possible to make inferences to the entire population studied. On the other hand, the coefficient of 0.566 indicates a moderate positive correlation, ratifying the rejection of the null hypothesis and suggesting a notable but less intense influence compared to the first relationship.

4 Conclusions

The results obtained in the study confirm a high positive and significant correlation between cooperative learning and quantitative reasoning in undergraduate mathematics students at a private university in Lima, Peru. This relationship is evidenced by a Spearman correlation coefficient of 0.808 and a significance of 0.000. In addition, a moderate positive correlation was found between the representation dimension of quantitative reasoning and cooperative learning, with a correlation coefficient of 0.566 and a significance of 0.000. These findings highlight the importance of cooperative learning as an effective teaching strategy to improve not only students' quantitative skills, but also their ability to work in teams and collaborate effectively.

The high correlation observed suggests that didactic strategies that foster positive interdependence, face-to-face interaction, individual responsibility and the development of social skills have a significant impact on students' academic performance. The implementation of dynamics that promote cooperation and group evaluation also appears to

be crucial for the comprehensive development of quantitative and collaborative competencies. The study data show that 67.7% of the participants indicated that they totally agree and agree with didactic strategies that promote positive interdependence, while 71% expressed agreement with face-to-face interaction. Likewise, 65.2% of the students supported individual responsibility and 71.9% positively valued the development of socioemotional skills. These percentages reinforce the relevance of collaborative strategies in the educational context.

This study presents some limitations that should be considered when interpreting the results. First, the sample size, although adequate for the analysis performed, limits the generalization of the findings to other populations and educational contexts. In addition, the research was conducted in a single private university in Lima, which may not reflect the diversity of experiences and educational contexts of other institutions. The methodology used, based on surveys and quantitative analysis, although robust, could benefit from the inclusion of qualitative approaches to deepen the understanding of students' perceptions and experiences.

To extend and validate the findings of this study, future research with larger and more diverse samples, including both public and private universities, and from different geographic regions, is recommended. Likewise, it would be beneficial to explore the implementation of mixed methodologies that combine quantitative and qualitative approaches to obtain a more complete picture of the impact of cooperative learning on the development of quantitative and collaborative skills. In addition, it is suggested to investigate the long-term impact of cooperative learning on students' academic and professional performance, as well as to evaluate the effectiveness of different cooperative didactic strategies in various disciplines beyond mathematics. Finally, future studies could analyze the role of technology and digital tools in facilitating cooperative learning and its influence on quantitative reasoning, exploring how digital representations can further enhance collaboration and learning among students. Moreover, at present, it would be pertinent to consider the application of data science and artificial intelligence techniques to this research, as they could provide a deeper and more generalizable understanding of the phenomena studied.

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Application of the Linear Model on the Optimal Fleet Calculation for Internal Transportation of a Peruvian University

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Abstract. The present study focuses on optimizing the internal transportation fleet of a Peruvian university using a linear programming model to adjust the size of the fleet. Through a quantitative and descriptive approach, user data was collected at 10 stops for 30 days, where a linear programming mathematical model was applied to optimize the size of the internal transport fleet, the solution of which was achieved through the use of the Solver add-on Excel. The results indicated that the optimal fleet is 2 units, which improves transportation planning and management, providing a more effective and satisfactory service. The research highlights the need for formal optimization methods to address university-level mobility problems. It demonstrates that route optimization can significantly reduce congestion and improve operational efficiency, contributing to a more sustainable and efficient transport service.

Keywords: Route optimization · internal transportation · linear programming · fleet management · Operational efficiency

1 Introduction

There is not a single day when humans do not use transportation, which underlines the importance of transportation systems in meeting mobility needs. These systems are related to economic, quality, and quantity factors, which present complexities that should not be excuses to solve the various problems of the system. For this reason, internal controls are implemented in the administration of transport companies, which allow goals and objectives to be achieved, thus guaranteeing adequate user satisfaction [1].

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In today's increasingly demanding environment, fleet optimization takes on significant value to ensure that products arrive at the right time and place. This service helps companies improve customer relationships, increase customer satisfaction, and improve business management, which often translates into increased profits, and greater employee motivation, and therefore, greater efficiency [2]. Among the previous studies, one was found that addresses fleet optimization through a life cycle cost approach and advanced techniques such as genetic algorithms and ant colony optimization, highlighting the effectiveness of these methodologies in solving large fleet design problems, efficient and realistic manner. The simulations demonstrate its ability to manage large fleets with near-optimal results, providing practical and fast solutions compared to conventional methods. [3]; another that investigates how operational fleet optimization and fleet management are crucial for shared mobility services, highlighting the importance of adequate fleet sizing from the start [4]; and a third study that formulates a MILP model that takes into account the substitution relationships between types and minimizes the total direct cost of the rail car under given rail car availability constraints and a predefined maximum number of types [5].

In Peru, buses, buses, and combis make up the traditional public transport most used on urban routes. However, this system faces a great challenge in terms of service quality, since the demand exceeds the capacity of the vehicles [6]. Currently, in Lima, there are 375 companies authorized to carry out urban transportation with 24,223 transportation units, which face competition from pirate services with obsolete units. However, many of these companies lack a strategy for the renewal and acquisition of new vehicle units to improve service [7].

Transportation is essential within an organization since the success of a supply chain is related to the proper design and use of the fleet system. However, this service presents problems, such as determining the size of the vehicle fleet and the appropriate routes to follow [8].

Large university campuses require an internal transportation system that can satisfy the transportation of teachers, students, and workers in time and space. If this service is carried out empirically, without considering the capacities of the buses, peak times, and transport flow during the day, it is necessary to apply formal optimization methods that provide effective solutions.

"Serverless Platforms" explores the use of deep neural network models to predict downtime in software containers and thus optimize their performance [9]. In a similar context, the study "Supervised Machine Learning for Link Prediction Using Path-Based Similarity Features" (IEEE, 2020) implements advanced prediction techniques to improve predictions in networks [10]. Similarly, in our study we use the Solver plugin to forecast and optimize the most efficient vehicle fleet, thus seeking to improve operational management.

The linear programming model represents an effective method for solving problems by relating linear variables with the problem conditions (constraints) towards a single objective. In this sense, a proposal is presented by applying a linear model to optimally adjust the size of the internal transport fleet. The objective of this research is to improve the planning and management of internal transportation in the university city to provide a more effective and satisfactory service for the university community.

2 Methodology

A. Type of Methodology

The present research is descriptive with a quantitative approach since its main objective is to optimize the internal transportation fleet of a national university in Peru. The number of users who get on and off the 10 stops on the perimeter of the university city that gives access to the various faculties and departments of the university was analyzed.

Descriptive research is carried out when you want to describe reality, in all its main components. It is the type of research that aims to describe some fundamental characteristics of homogeneous sets of phenomena, using systematic criteria that allow establishing the structure or behavior of the phenomena under study, providing systematic information [11].

Quantitative research tries to determine the strength of correlation between variables, the generalization, and objectification of the results through a sample to interfere with the population from which the sample comes. After the correlation study, it aims, in turn, to make causal interference that explains why things happen or do not happen in a certain way [12].

B. Data Collection

A collection of information was carried out on users who get on and off at ten (10) stops that are part of the internal transportation of a Peruvian university for thirty (30) days from 12:30–1:00 p.m. For data collection, the observation method was carried out and Excel was used to record the corresponding data in tables. All this information is required for the process in the simulation model.

C. Data Selection

For the analysis and selection of the information collected, some statistical theories were used such as standard deviation for the limits of the restrictions, that is, it is carried out in order not to generate a dispersion of data and thus better understand the data sets, for example. On the other hand, the average of the data collected is used in order to generate the central tendency in order to have greater precision in the calculations. Finally, the data is entered into the Excel add-in (Solver) in order to generate the required fleet based on each whereabouts.

D. Data Processing

Solver Excel is a specialized Excel add-in for model simulation, with which you can model the fleet of buses required at each stop. Subsequently, the data obtained is evaluated by making a comparison of the maximum number of fleet required at each stop and making improvement proposals for the complete route at the ten (10) stops of the university city.

3 Results

3.1 Data

The data collected shows whereabouts that have greater user congestion. The number of users who get on and off at each stop is shown in Table 1. Statistical calculations determined the mean and standard deviation to avoid a large dispersion of data and generate limits on the restrictions.

Based on the thirty (30) days of observation of the internal transportation service, it can be seen that users presented a situation of discomfort when they were not able to get on and off the buses when they were congested. Taking this situation as a reference, a maximum capacity of seventy-eight (78) users is considered, that is, the ideal number of people transported.

The data collected by days, whereabouts, and number of people getting on and off are shown in Table 1. Statistical calculations were performed, determining the mean and standard deviation to avoid a large dispersion of data and generate limits on the restrictions.

Table 1. Data collected from days 1 and 2.

	DAY 1		DAY 2	
Users	They go up	They go down	They go up	They go down
Amount in whereabouts 1	10	8	12	13
Amount in whereabouts 2	13	12	15	14
Amount in whereabouts 3	30	15	33	10
Amount in whereabouts 4	13	20	17	28
Amount in whereabouts 5	1	1	0	3
Amount in whereabouts 6	1	3	1	2
Amount in whereabouts 7	23	35	17	26
Amount in whereabouts 8	20	25	19	21
Amount in whereabouts 9	2	5	1	7
Amount in whereabouts 10	15	14	17	20
Amount initial	70		68	

The study began at bus stop 1. It was observed that bus stops 5 and 6 had fewer users, while bus stops 7 and 8 had a higher number due to their location on main avenues.

Statistical calculations are made from the collected data, the average, and the standard deviation so that the group of data does not generate a large dispersion, after which limits are generated to the restrictions, when using the collected data, some of them are shown in Table 1, the process is detailed below. Table 2 shows the results obtained.

A standard deviation is added and subtracted from the data shown in Table 2, expressed in the following equation:

$$\bar{x} \pm 1\sigma \tag{1}$$

In this way, the data presented in Table 3 are obtained. This is to restrict where the largest amount of the population is located and, in this way, a degree of reliability can be provided to the limits.

The standard deviation indicates the degree of dispersion shown by the data set, that is, the larger the standard deviation, the more dispersion there is [13]. Therefore, Eq. (1)

Table 2. Obtaining the mean and standard deviation.

Media		Approximate		Desv. Standard	
They go up	They go down	They go up	They go down	They go up	They go down
11.03	12.93	11.00	13.00	4.98	6.83
17.20	18.87	17.00	19.00	5.68	7.03
25.73	26.70	26.00	27.00	8.69	12.56
23.63	30.57	24.00	31.00	9.25	9.27
0.67	2.37	1.00	2.00	0.76	1.27
0.33	3.00	0.00	3.00	0.66	1.53
36.13	38.77	36.00	39.00	12.87	12.04
27.93	28.87	28.00	29.00	9.97	10.60
1.40	5.07	1.00	5.00	1.33	2.27
16.10	20.70	16.00	21.00	4.71	6.02
74.47		74.00		4.08	

indicates a higher degree of reliability, since the data are around the mean, therefore there is no great dispersion.

Table 3. Limits of restrictions.

Media -1 σ		Media + 1 σ		Initial amount	
Goes up	They go down	Goes up	They go down	Media -1 σ	Media + 1 σ
6.05	6.10	16.01	19.77	70.38	78.55
11.52	11.84	22.88	25.90		
17.05	14.14	34.42	39.26		
14.38	21.29	32.89	39.84		
-0.09	1.09	1.42	3.64		
0.00	1.47	0.99	4.53		
23.26	26.73	49.01	50.81		
17.96	18.26	37.90	39.47		
0.07	2.79	2.73	7.34		
11.39	14.68	20.81	26.72		

3.2 Model Simulation

Wwas created to obtain the required fleet, defining the variables and restrictions in Excel with the Solver program. The objective function was to maximize the number of

passengers and determine the optimal fleet by dividing by the maximum capacity of 78 passengers. The objective function and restrictions were defined based on the mean and standard deviation.

Equation (2) is the objective function of the problem presented in this research work.

$$\text{Máximizar } Z \begin{cases} x_1 + \sum_{i=2}^{h} x_i - \sum_{j=12}^{h+10} x_j \\ \text{Para } h = 2,3 \ldots 11 \\ x_1 \ , \ \text{para } h = 1 \\ \text{Donde } h = 1,2,3 \ldots 11 \\ \text{S. a.} \\ \bar{u}_k - s_k \leq x_k \leq \bar{u}_k + s_k \end{cases} \tag{2}$$

The function is defined in two parts and the restrictions are 21 in total.

Where:

- $\bar{u}_k$: sample average of the variable k
- s_k: sample standard deviation of the variable k

With the variables already found, the amount of fleet required can be calculated considering 78 the maximum capacity for the bus:

$$\text{Cantidad de flota requerida}: \frac{x_1 + \sum_{i=2}^{11} x_i - \sum_{j=12}^{21} x_j}{78} \tag{3}$$

The number of users who get on and off the transport at each of the ten (10) stops are defined as variables, which are a total of twenty-one (21), see Table 4.

The restrictions are defined based on the minimum and maximum quantities measured, obtained from the mean plus and minus the standard deviation respectively, see Table 5.

Table 6 shows the fleet required at each location to comply with the requested conditions, which in turn are subject to the restrictions. The interpretation of the results gives the answer that a fleet of at least 1 unit is required for the cases of least user congestion, and 3 units in the most extreme case of congestion. As a final and therefore optimal response, there are 2 bus units as a fleet so that users do not have discomfort problems and, above all, the service is the most appropriate.

After the simulation, the sensitivity analysis is presented, given by the Excel add-in report (Solver).

From Fig. 1 the following is interpreted:

- $0 < Cx1 < \infty$ the coefficient can vary in these limits, when it tends to 0 it means that each person requires less space on the bus, on the other hand, when it is at infinity people require more space to travel on the bus but if it is met In these limits the value of 78.54 is optimal. The analysis is similar up to the variable x11

In addition, when people go down from variables X12 to X21.

Table 4. Variables inserted in solver.

Variables	Description
x1	Number of initial passengers on the bus
x2	Number of passengers boarding at "Whereabouts 1"
X3	Number of passengers boarding at "Whereabouts 2"
x4	Number of passengers boarding at "Whereabouts 3"
X5	Number of passengers boarding at "Whereabouts 4"
X6	Number of passengers boarding at "Paradero 5"
X7	Number of passengers boarding at "Paradero 6"
X8	Number of passengers boarding at "Paradero 7"
X9	Number of passengers boarding at "Paradero 8"
x10	Number of passengers boarding at "Paradero 9"
X11	Number of passengers boarding at "Paradero 10"
x12	Number of passengers getting off at "Whereabouts 1"
X13	Number of passengers getting off at "Whereabouts 2"
X14	Number of passengers getting off at "Whereabouts 3"
X15	Number of passengers getting off at "Whereabouts 4"
X16	Number of passengers getting off at "Paradero 5"
X17	Number of passengers getting off at "Paradero 6"
X18	Number of passengers getting off at "Paradero 7"
X19	Number of passengers getting off at "Paradero 8"
X20	Number of passengers getting off at "Paradero 9"
X21	Number of passengers getting off at "Paradero 10"

- $\infty < Cx12 < 0$, regardless of the space vacated by people when descending, will not affect the optimal point.

From Fig. 2 the following is interpreted:

- $62 < r1 < \infty$ the passenger limits that must be at least 62 at the beginning for the fleet to be adequate.
- $(-)3 < r2 < \infty$, a maximum of 3 people can get off and the number of passengers can go up to fill the bus.
- $0 < r3 < \infty$, a maximum of 0 people can get off and the number of passengers can go up to fill the bus. The analysis is similar to constraint 42.

So on in all the restrictions, on the other hand, the shadow prices will be analyzed, which indicates the following:

- The shadow price equal to zero (0) means that this restriction is not binding with the feasible region of the problem (r1 to r11 and r33 to r42). Since the lower limit of the

Table 5. Constraints inserted in the Excel complementary program (solver).

Restrictions					
R1	70,384	<=	79	<=	78.550
R2	6.05	<=	16	<=	16.012
R3	11.52	<=	23	<=	22.878
R4	17.05	<=	3. 4	<=	34.419
R5	14.38	<=	33	<=	32.886
R6	0	<=	1	<=	1.425
R7	0	<=	1	<=	0.994
R8	23.26	< =	49	<=	49.006
R9	17.96	< =	38	<=	37.902
R10	0.07	<=	3	<=	2.729
R11	11.39	<=	21	<=	20.815
R12	6,101	<=	6	<=	19.766
R13	11,836	<=	12	<=	25.897
R14	14,144	<=	14	<=	39.256
R15	21,294	<=	21	<=	39.839
R16	1,094	<=	1	<=	3.639
R17	1,469	<=	1	<=	4.531
R18	26,727	<=	27	<=	50.806
R19	18,262	<=	18	<=	39.472
R20	2,793	<=	3	<=	7.340
R21	14,682	<=	15	<=	26.718

number of people who board at the first stop is a restriction where what is sought is the upper limit, this does not affect the optimal point which is the maximum point of the number of people who board and, in this way, find the maximum fleet.

- If the shadow price of a constraint is 1, it means that a unit increase in that constraint will result in a unit increase in the optimal value of the objective function. To find a maximum fleet, these depend on the number of people on the bus. Therefore, the restriction limits affect the optimal point such as the restrictions r12 to r21, which represent the lower limit of their respective restrictions, therefore, the shadow price 1 indicates that by increasing the lower limits of the people who descend, they will be the minimum of these restrictions since the number of people to be downloaded is reduced, for example in r12 the limit is $6 < r12 < 19$, but if the shadow price is added the minimum number of people to be downloaded will be $7 < r12 < 19$; that is, r12 has fewer values to take.

Table 6. Results of the objective functions when inserting in Solver.

Result	
Maximum	2.298
FO	
Z1	79
Z2	88
Z3	100
Z4	119.78
Z5	131.37
Z6	132
Z7	131.227
Z8	153.51
Z9	173.146
Z10	173
Z11	179.21

Celdas de variables

Celda	Nombre	Final Valor	Reducido Coste	Objetivo Coeficiente	Permisible Aumentar	Permisible Reducir
D41	X1incio	78.54971263	0	1	1E+30	1
D42	X2 suben	16.01248527	0	1	1E+30	1
D43	X3 suben	22.87754196	0	1	1E+30	1
D44	X4 suben	34.41916537	0	1	1E+30	1
D45	X5 suben	32.88641608	0	1	1E+30	1
D46	X6 suben	1.42476471	0	1	1E+30	1
D47	X7 suben	0.994227886	0	1	1E+30	1
D48	X8 suben	49.00600777	0	1	1E+30	1
D49	X9 suben	37.90201994	0	1	1E+30	1
D50	X10 subei	2.728727678	0	1	1E+30	1
D51	X11 subei	20.8149798	0	1	1E+30	1
D52	X12 bajar	6.100686886	0	-1	1	1E+30
D53	X13 bajar	11.83602764	0	-1	1	1E+30
D54	X14 bajar	14.14350697	0	-1	1	1E+30
D55	X15 bajar	21.29422573	0	-1	1	1E+30
D56	X16 bajar	1.094055088	0	-1	1	1E+30
D57	X17 bajar	1.468717013	0	-1	1	1E+30
D58	X18 bajar	26.72741095	0	-1	1	1E+30
D59	X19 bajar	18.2617448	0	-1	1	1E+30
D60	X20 bajar	2.793383558	0	-1	1	1E+30
D61	X21 bajar	14.68192378	0	-1	1	1E+30

Fig. 1. Sensitivity analysis for the variables.

N42	F23 FO	16.01248527	1	16.01248527	1E+30	9.958303876
N43	F24 FO	22.87754196	1	22.87754196	1E+30	11.35508393
N44	R25 FO	34.41916537	1	34.41916537	1E+30	17.37166407
N45	R26 FO	32.88641608	1	32.88641608	1E+30	18.50616548
N46	R27 FO	1.42476471	1	1.42476471	1E+30	1.42476471
N47	R28 FO	0.994227886	1	0.994227886	1E+30	0.994227886
N48	R29 FO	49.00600777	1	49.00600777	1E+30	25.74534887
N49	R30 FO	37.90201994	1	37.90201994	1E+30	19.93737321
N50	R31 FO	2.728727678	1	2.728727678	1E+30	2.657455355
N51	R32 FO	20.8149798	1	20.8149798	1E+30	9.429959593
N52	R33 FO	6.100686886	0	19.76597978	1E+30	13.66529289
N53	R34 FO	11.83602764	0	25.89730569	1E+30	14.06127804
N54	R35 FO	14.14350697	0	39.25649303	1E+30	25.11298606
N55	R36 FO	21.29422573	0	39.8391076	1E+30	18.54488187
N56	R37 FO	1.094055088	0	3.639278245	1E+30	2.545223157
N57	R38 FO	1.468717013	0	4.531282987	1E+30	3.062565974
N58	R39 FO	26.72741095	0	50.80592238	1E+30	24.07851143
N59	R40 FO	18.2617448	0	39.47158853	1E+30	21.20984374
N60	R41 FO	2.793383558	0	7.339949775	1E+30	4.546566217
N61	R42 FO	14.68192378	0	26.71807622	1E+30	12.03615244

Restricciones

Celda	Nombre	Final Valor	Sombra Precio	Restricción Lado derecho	Permisible Aumentar	Permisible Reducir
L41	R1 FO	70.3836207	0	0	1E+30	8.166091934
L42	R2 FO	6.054181395	0	0	1E+30	9.958303876
L43	R3 FO	11.52245804	0	0	1E+30	11.35508393
L44	R4 FO	17.0475013	0	0	1E+30	17.37166407
L45	R5 FO	14.38025059	0	0	1E+30	18.50616548
L46	R6 FO	0	0	0	1E+30	1.42476471
L47	R7 FO	0	0	0	1E+30	0.994227886
L48	R8 FO	23.2606589	0	0	1E+30	25.74534887
L49	R9 FO	17.96464673	0	0	1E+30	19.93737321
L50	R10 FO	0.071272322	0	0	1E+30	2.657455355
L51	R11 FO	11.3850202	0	0	1E+30	9.429959593
L52	R12 FO	6.100686886	1	0	6.100686886	13.66529289
L53	R13 FO	11.83602764	1	0	11.83602764	14.06127804
L54	R14 FO	14.14350697	1	0	14.14350697	25.11298606
L55	R15 FO	21.29422573	1	0	21.29422573	18.54488187
L56	R16 FO	1.094055088	1	0	1.094055088	2.545223157
L57	R17 FO	1.468717013	1	0	1.468717013	3.062565974
L58	R18 FO	26.72741095	1	0	26.72741095	24.07851143
L59	R19 FO	18.2617448	1	0	18.2617448	21.20984374
L60	R20 FO	2.793383558	1	0	2.793383558	4.546566217
L61	R21 FO	14.68192378	1	0	14.68192378	12.03615244
N41	R22 FO	78.54971263	1	78.54971263	1E+30	8.166091934

Fig. 2. Sensitivity analysis for restrictions.

Furthermore, the same thing happens in the restrictions r22 to r32 of the upper limit where the aim is to increase the number of people, for example, in r2 at the beginning it is $6 < r23 < 16$ but adding the increase in the shadow price increases the number of people at increase $6 < r23 < 17$ that is, the values of r2 increase.

4 Discussion and Conclusions

The simultaneous use of simulation and optimization in the planning of logistics operations allows us to suggest the optimal number of transport vehicles, minimizing idle time and maximizing the level of customer service [14]. Compared to other studies, this one does not require simulation due to the simplicity and cyclicity of the route. The bibliographic review highlights the usefulness of simulation for the optimization and sizing of fleets in the internal transportation of universities. The study revealed that the university's current fleet does not meet demand, generating discomfort and risks to the health and safety of users. The optimal bus fleet determined is 2 units.

Experts in Operations Research and Logistics have investigated vehicle sizing, using heuristic algorithms to find feasible and high-quality solutions in a reasonable time [15]. Although these methods can generate approximate solutions, the present study provides accurate results.

In conclusion, the optimal fleet size is 2, which improves the planning and management of internal transportation in the university city, providing a more effective and satisfactory service for the university community.

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Transforming Graduate Data for Strategic Decision Making: A Business Intelligence Approach in Higher Education

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Abstract. The information about graduates from a higher education institution is crucial for enhancing curriculum design and academic training. The Graduate Tracking Unit of the Naval Technological Center of Higher Technological Institute (IST CETNAV) is responsible for collecting this data, which is not utilized effectively. Therefore, this paper proposes the application of Business Intelligence to improve the data processing and analysis, with development based on the CRISP-DM methodology. The provided data was analyzed to explore relationships among variables. The ETL process, which involves extraction, transformation, and loading of personal data, academic background, and employment status of graduates, was implemented using Power BI. The result is a solution that facilitates strategic decision-making by presenting an interactive dashboard with graphical visualizations that reflect clear and precise information on the indicators established by the institute's graduate tracking unit, thereby enhancing information management.

Keywords: Graduates · Business Intelligence · Strategic · Decision-Making · Power BI

1 Introduction

In the realm of higher education, effective management of graduate data has become a crucial aspect of enhancing educational quality and strategic decision-making within institutions. The application of business intelligence in this context has proven to be a powerful tool for transforming collected data into meaningful insights that drive continuous improvement in the educational sector [1, 2].

Previous studies highlight the importance of business intelligence in managing the large volumes of data required for institutional accreditation in higher education institutions in Colombia, emphasizing the relevance of implementing technological solutions to optimize the graduate tracking process [3]. Similarly, universities in Mexico, within a competitive environment, have also adopted these tools to improve academic, administrative, and financial management, as well as to monitor graduate performance and enhance

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educational decision-making [4]. In this context, the present study focuses on exploring how the implementation of business intelligence solutions in the graduate tracking process can facilitate the transformation of data into informed strategic decisions. With a specific focus on IST CETNAV, we aim to analyze the impact of this implementation on optimizing the processing and analysis of graduate information, as well as identifying areas for improvement in the academic training offered by the institution. The significance of this study lies in the need to leverage information generated from graduate tracking to improve educational quality, adapt academic programs to labor market demands, and ensure graduate employability. By exploring how business intelligence can enhance strategic decision-making in the educational field, the goal is to contribute to the advancement of data management practices in higher education institutions.

Through a literature review, a detailed description of the methodology used, and an analysis of the results obtained in this study, we aim to provide a comprehensive view of the impact of business intelligence on transforming graduate data and its influence on strategic decision-making in the educational context. This approach will not only benefit the Naval Technology Center but also provide valuable insights to other academic institutions seeking to improve their graduate tracking processes and strengthen their educational quality.

2 Related Works

The implementation of Business Intelligence (BI) solutions in higher education institutions has proven to be a powerful tool for enhancing educational quality and strategic decision-making. Various studies have addressed this topic, presenting successful cases that highlight the benefits and challenges of these implementations.

In Chiclayo, Mexico, a BI solution was proposed to support decision-making in the academic management of a university in the Lambayeque department [4]. The hypothesis posited is that the implementation of a BI solution can significantly improve academic management by reducing report generation time and increasing the number of available reports. The methodology employed is Kimball's, and the study is based on data directly obtained from the institution. The results indicate that the BI solution provides valuable contributions to knowledge generation that support decision-making in university academic management.

Another success story comes from Ecuador, focusing on the evaluation of higher education institutions during the accreditation process. In Viviana Malavé's study [5] a Datamart was designed using Integration Services in Visual Studio, based on quantitative indicators selected from surveys and interviews. The implementation of ETL (Extract, Transform, Load) processes allowed for more efficient data management, highlighting the importance of BI tools for institutional evaluation.

Gary Torres' study [6] focuses on implementing a BI platform for tracking graduates at the Universidad Politécnica Estatal del Carchi (UPEC), aiming to optimize decision-making through the collection and analysis of relevant information. It is proposed that Ralph Kimball's methodology will enhance data management. The research employed a mixed qualitative-quantitative approach and applied the ETL methodology with tools such as Tableau Prep Builder. Results include a Data Mart that enables the visualization of

management indicators through a dashboard, facilitating access to updated information. The conclusions emphasize improvements in graduate information management and the potential to expand the Data Mart into a Data Warehouse to centralize UPEC's historical information.

David Fuentes' study [7] proposes a dimensional model adapted to improve data management in academic, research, and graduate tracking processes at public higher education institutions in Colombia. The hypothesis is that this model would facilitate self-assessment and compliance with the National Accreditation Council (CNA) standards. Through a methodology that included data collection, requirement identification, development, and validation of six-dimensional models, as well as a pilot implementation at the Universidad Industrial de Santander, 100% adaptability to identified requirements and high user satisfaction were achieved. Results indicate that the model not only optimizes data organization and analysis but also enhances strategic decision-making, contributing to educational quality and the accreditation process in public higher education institutions.

Jarley Castillo's study [8] analyzes how BI can improve graduate information systems in higher education institutions (HEIs) by optimizing data tracking and management to strengthen communication and support accreditation processes. Through a mixed approach that included literature review and case studies, it was found that BI implementation in HEIs results in better operational efficiency, more effective graduate tracking, and high staff satisfaction by providing accurate and timely data for decision-making. However, challenges such as the need for training and data integration were identified. In conclusion, BI is a valuable resource for optimizing graduate systems management, improving communication, and supporting accreditation, provided that investment in training and a data-oriented organizational culture is established.

These studies demonstrate that the implementation of BI solutions in higher education institutions not only improves academic management and institutional evaluation but also contributes to the continuous enhancement of educational quality. Business Intelligence enables institutions to leverage data to strengthen graduate employability and stay at the forefront in a constantly evolving educational environment.

At IST CETNAV there is a need to implement a BI solution due to the large volume of information handled in the graduate tracking process. Currently, this process is conducted manually and inefficiently, which hampers the consolidation and effective analysis of the obtained data. Implementing a BI solution at IST CETNAV would not only improve the graduate tracking and data analysis process but also contribute to enhancing educational quality and the relevance of the programs offered by the institution.

3 Methodology

This study adopted a mixed-methods approach, integrating both qualitative and quantitative aspects. An extensive review of relevant literature and documentation was conducted to understand the current state of business intelligence and procedures related to graduate tracking. Additionally, detailed interviews were carried out with the personnel responsible for graduate tracking and the institution's quality assurance unit to obtain key information regarding data collection and analysis. The CRISP-DM methodology was

employed, recognized in the field of business intelligence for its focus on Data Warehousing and Data Mining, and supported by international standards [9]. CRISP-DM provides a robust and reliable framework, facilitating its use and enabling the creation of a dimensional data model that supports decision-making. Its iterative process promotes feedback and continuous improvement, and its neutrality regarding tools makes it adaptable to various projects.

The choice of the CRISP-DM model for this study is justified by its clear and methodical structure, which aids in defining objectives, data collection, and results evaluation. By breaking down the process into well-defined phases, it allows for a systematic approach that minimizes confusion and maximizes efficiency. Its adaptability to diverse contexts and its foundation in the practical experience of professionals ensure its relevance in real-world situations [10]. The cyclical nature of the model allows for adjustments based on results, promoting continuous improvement and making CRISP-DM an ideal tool for addressing the challenges of graduate tracking and maximizing the impact of academic programs.

In terms of population and sample, the study focused on the staff of the Graduate Tracking Unit and the Quality Assurance Unit of the institution, which are responsible for developing graduate tracking strategies. Key indicators were established based on the External Evaluation Model for Technical and Technological Institutes for Accreditation 2024 [11], with the aim of improving curriculum design and academic training processes. The use of business intelligence tools, such as Power Query, will allow for the efficient reorganization of graduate survey data, eliminating unnecessary information and retaining only relevant data for the study, thereby facilitating more effective analysis and contributing to the achievement of the established objectives.

4 Development

This section details the development process of a Business Intelligence (BI) solution aimed at enhancing data collection and analysis for the Graduate Tracking Unit at IST CETNAV. The primary objective is to improve compliance with CACES accreditation standards. The primary objective is to enhance compliance with CACES accreditation standards. The development process follows a structured approach encompassing four key phases: business understanding, data understanding, data preparation, and modeling. The initial phase focuses on understanding the current operations of the Graduate Tracking Unit to identify areas for improvement. This includes understanding the need for more detailed information about graduates, such as geographic distribution and acquired competencies. Subsequent phases delve into familiarizing with the data, assessing its quality, and identifying relationships to formulate initial hypotheses. Data preparation involves the meticulous selection, cleaning, and transformation of relevant data from graduate surveys. These surveys capture general information about graduates, academic backgrounds, and acquired skills. Finally, the modeling phase utilizes dimensional modeling techniques to design a structure that facilitates data integration and allows for detailed queries for analyzing graduate data. This structured approach ensures an efficient and well-defined development process for the business intelligence solution.

4.1 Business Understanding

Understanding the requirements and objectives of the project from a business perspective is crucial [9], In this phase, the focus was on comprehending the operations of the Graduate Tracking Unit at IST CETNAV, with the goal of enhancing data collection and analysis to meet CACES accreditation standards. After obtaining authorization and conducting meetings with relevant personnel, the need for more detailed information about graduates was identified, including their geographic distribution and competencies. It was proposed to develop a dimensional model to efficiently integrate and analyze this information through a Business Intelligence solution.

4.2 Understanding the Data

This phase involves the initial collection of data to familiarize with it, assess its quality, and identify relationships that allow for the formulation of initial hypotheses [9]. Data is collected from the Graduate Tracking Unit, examined, and selected for inclusion in the solution. This data is obtained directly from survey forms, which contain general information about graduates and their academic backgrounds, including the skills acquired during their educational process. These competencies are categorized into two types of questions: generic questions, covering areas such as curriculum structure, employment status, resources, and professional relationships; and specific questions (Table 1), which vary according to the program offered at the institute, such as naval sciences, naval mechanics, electricity, and electronics.

4.3 Data Preparation

This phase involves analyzing the data to identify key elements for selection, cleaning, and transformation [9]. The data preparation process for the Business Intelligence solution begins with collecting data from the Graduate Tracking Unit, obtained directly from the spreadsheet generated by Google Forms. Next, a new data file is created, defining the tables and columns that will hold the relevant information for the solution. Information corresponding to each column is recorded in these tables, ensuring data integrity and consistency, as illustrated in Tables 2 and 3. Subsequently, the Extract, Transform, Load (ETL) process is carried out using Power BI. This involves performing the necessary operations to clean, integrate, and structure the data appropriately for further analysis in the Business Intelligence solution.

4.4 Modeling

This phase involves the application of modeling techniques or Data Warehousing [9]. The process begins with designing the dimensional model, which includes defining dimensional tables and the fact table. This design allows for the relationship of data obtained from the previous data preparation phase and facilitates the generation of queries for structured and comprehensible information analysis, as illustrated in Fig. 1.

For the Business Intelligence solution, measures were proposed based on the requirements of the Graduate Tracking Unit and the Quality Assurance Department of CETNAV, as shown in Table 4.

Table 1. Classification of question information by type and category.

Type	Category	Description	Observation
Generic skills	Professional relationship	Skills in communication, collaboration, conflict management and ethical behavior at work	These categories were de-fined within the structure of the survey
	Curricular structure	Skills linked to self-learning, time management, planning and analytical skill	
	Resources	Skills to search for and use information, use information and communication technologies (ICT) and manage resources	
	Job occupation	Ability to adapt, flexibility and ability to acquire new skills in order to function in various work environments	
Specific competencies	Knowledge	Understand the fundamental con-cepts and principles in a given field	These categories were identified based on the verbs used in the questions of this type and were related to Bloom's taxonomic levels
	Comprehension	Explain ideas or concepts clearly	
	Application	Use the knowledge acquired in practical situations	
	Analysis	Decompose complex information to understand its structure and operation	

(*continued*)

Table 1. (*continued*)

Type	Category	Description	Observation
	Assessment	Make critical judgments based on established criteria	
	Creation	Generate new ideas, solutions or products by combining knowledge and skills	

Table 2. Classification of question information by type and category.

Data Source	Dimension name	Description
PDF file with names, professional title and promotions of graduates	DIM_GRADUATES	Dimension that stores graduate data
PDF file with course name and degree information offered	DIM-COURSE	Dimension that stores courses data
Spreadsheet for each course with the data obtained from the surveys, promotion and year of graduation columns	DIM_PROMOTION	Dimension that stores data from the class in which they graduated
Spreadsheet for each career with the data obtained from the surveys, distribution column where the graduate is located	DIM_WORKPLACE	Dimension that stores data for the assigned distribution
Spreadsheet for each course with the data obtained from the surveys, column position held	DIM_POSITION	Dimension that stores data about the position you currently occupy
Spreadsheet for each race with the data obtained from the surveys, columns from G to BN, annual report and categorization prepared in Table 2	DIM_QUESTIONS	Dimension that stores data from questions classified by question type and categories according to the skills acquired and developed by graduates
Spreadsheet for each race with the data obtained from the surveys, columns from G to BN with row variation and annual report	DIM_RESPONSES	Dimension that stores data from the responses provided by graduates, according to the established scale
Spreadsheet for each race with the data obtained from the surveys, time stamp column	DIM_TIME	Dimension that stores data from the date on which the survey execution is recorded

Table 3. Fact Table.

Data Source	Fact name	Description
Data stored in each of the attributes established in the dimensions	FACT_OCCUPATION	Fact that stores each of the graduate's records

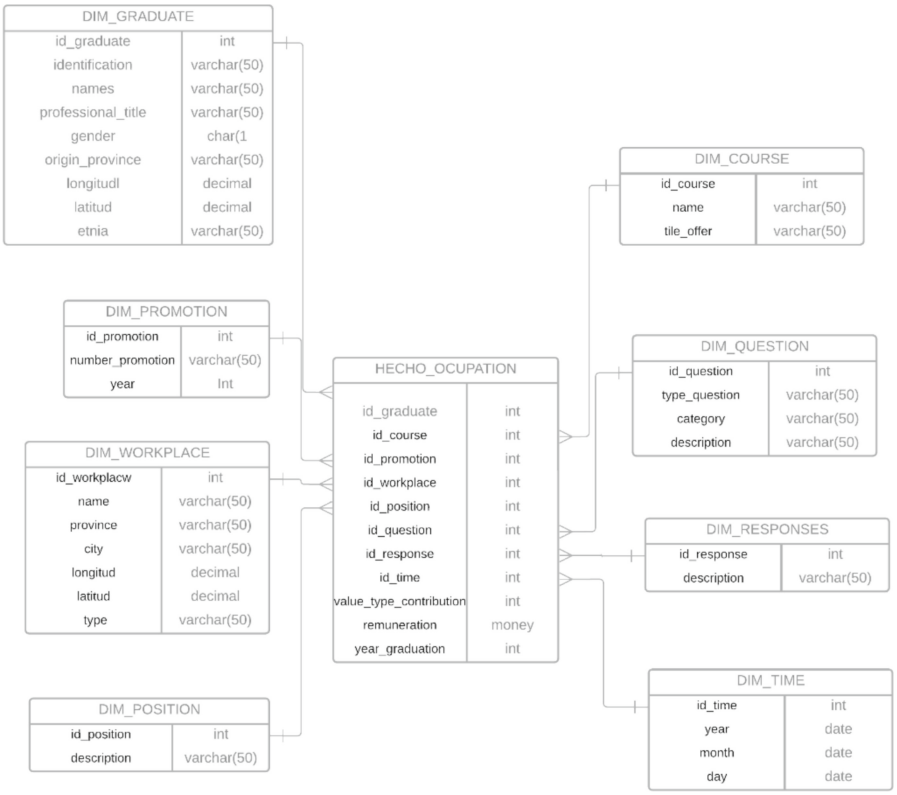

Fig. 1. Dimensional model.

To identify the indicators, the established measures and the opinions of the interviewees were considered. They agreed that the indicators to be evaluated are as follows: graduates by program, satisfaction with generic competencies acquired by graduates, and satisfaction with specific competencies acquired by graduates from the four courses, as detailed in Table 5.

Table 4. Fact Table.

Measure	Description
Number of graduates	Contains the number of graduates in the years 2020 and 2021 from the 4 courses
QtyQuestions CG	Contains a number of generic competency type questions by career
QtyQuestions CE	Contains a number of questions of specific competencies according to the category by career
Agreement	It contains all the answers to the questions that were answered in agreement and in total agreement for the type of questions generic competencies of the 4 courses
Neutral	It contains all the answers to the questions that were answered neither in agreement nor in disagreement for the type of generic competencies questions of the 4 courses
Disagreement	It contains all the answers to the questions that were answered in disagreement and in total disagreement for the type of generic competencies questions of the 4 courses
Total Questions Answered	It contains the number of answers to the generic skills type questions for each of the courses
Essential CE	It contains the number of answers valued as essential to the specific competency type questions according to each category of each of the courses
Important CE	It contains the number of answers rated as important to the specific competency type questions according to each category of each of the courses
Not important CE	It contains the number of responses rated as unimportant to the specific competency type questions according to each category of each of the majors
Indifferent CE	It contains the number of responses valued as indifferent to the specific competency type questions according to each category of each of the courses
Total EC Responses	It contains the total responses of all the assessments according to the categories of the specific competency-type questions for each of the courses
CE Reference	It contains the reference values obtained from the product of the number of graduates of each degree program and the number of questions according to each category of specific competency-type questions

4.5 Assessment

To analyze the effectiveness of our study, we utilized reliable survey data extracted from spreadsheets issued by Google Forms and annual reports from the unit, which

Table 5. Description of the indicators.

Indicator	Description
Graduates by course	Number of graduates in each of the four courses offered
Satisfaction of generic skills acquired by graduates	Degree of satisfaction of graduates in relation to the generic skills developed during their training
Satisfaction of specific skills acquired by graduates of the four courses	Degree of satisfaction of graduates in relation to the specific competencies developed during their training according to each of the categories related to Bloom's taxonomic levels in each of the four courses offered by the institution

contain detailed information about the graduates, ensuring that each data point meets the following criteria:

- Integrity: The coherence and validity of the data are verified, as it contains personal information about the graduates.
- Relevance: Relevant data is selected to identify trends in the graduates' education and career, including their program, naval division of employment, and job position, adding value to the data used in the analysis.
- Consistency: The consistency of information related to each graduate is maintained, ensuring synchronization and coherence of information across records.
- Availability: Data accessibility is ensured in a legal and secure manner in accordance with the privacy policy established by the Ecuadorian Navy and data protection regulations.

By applying these evaluation criteria to the data, we can guarantee the quality and reliability of the information used in our study.

4.6 Deployment

This phase involves the implementation or dissemination of the previously selected and evaluated models [9]. Based on the results obtained during the development of the Business Intelligence solution, a presentation session was conducted with the stakeholders from the benefiting units. During this session, the results presented in each report were explained. A notable improvement in data processing was highlighted, as evidenced by a comparison with the previous procedure. Whereas the former annual report was limited to providing basic information derived from survey tabulation, the new dimensional model enables the generation of more detailed reports on general graduate information and the competencies acquired during their training in various programs offered by the institute, categorized into generic and specific competencies.

Regarding response times, significant changes were observed. Previously, processing graduate information took between 2 and 3 months to produce a basic report for each survey dimension. However, with the developed dimensional solution, this process now takes approximately 2 min from the initial dashboard screen.

The reports generated by the dashboard have proven to be valuable tools for analyzing relevant data on IST CETNAV graduates, significantly contributing to strategic decision-making in the educational domain.

5 Results

The business intelligence and data analysis solution applied to the graduate tracking process enabled the implementation of user-friendly dashboards and control panels. These tools facilitate the articulation of information according to the specific queries that users wish to conduct, allowing the requirements requested by the tracking unit to be represented and designed by the institution's graduates. As a result of the Business Intelligence solution, the following dashboards were created:

5.1 Dashboard Graduate General Information

The dashboard design provides a clear layout of elements: on the left, a filter indicating the graduation year to analyze, followed by a ring chart displaying the number of graduates by degree program. Additionally, a second ring chart summarizes the number of graduates by province of origin. On the right side, there is a stacked bar chart reflecting the number of students assigned to various naval divisions across different provinces of the country. Directly below, a bar chart summarizes the percentage of responses obtained according to the evaluations established for each of the generic competencies of the four programs offered by the institute. In the center of the dashboard, there is a map showing information about the provinces with the highest number of graduates, along with a menu containing the logo of each program, linked to detailed reports on specific skills, as illustrated in Fig. 2.

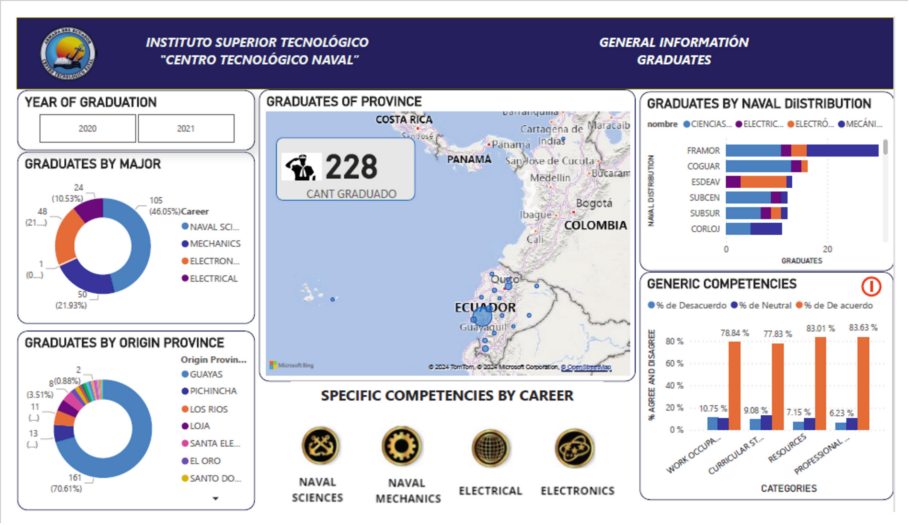

Fig. 2. Initial report screen.

5.2 Dashboard Graduate General Information

In Fig. 3, a series of graphic elements are shown containing information about the percentage of graduates in the four programs offered by the institute. Following this, a matrix reflects information on responses categorized as Agree, Neutral, and Disagree regarding the generic competencies achieved during the academic training process and the percentage of satisfaction with the generic competencies acquired. Additionally, in the upper right corner, there is a back button that allows users to return directly to the main page.

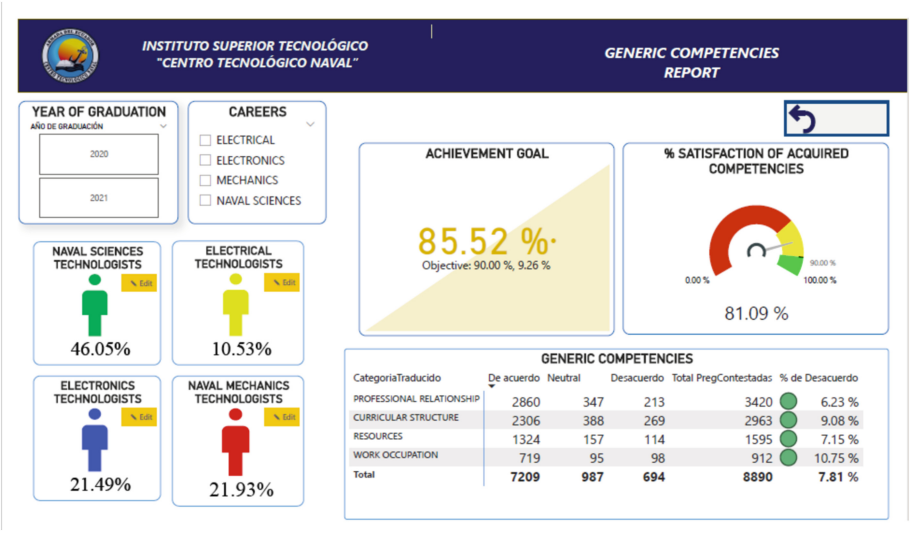

Fig. 3. Report generic competencies.

5.3 Dashboard of Specific Electronics Career Competencies

The report on specific competencies for the Electronics program includes a set of graphical visualizations that reflect information on reference values by categories of specific competencies, a summary of the total number of questions answered according to the established evaluations, percentages of satisfaction with the specific competencies acquired for each category related to Bloom's taxonomy levels, and KPI compliance for each category, as shown in Fig. 4.

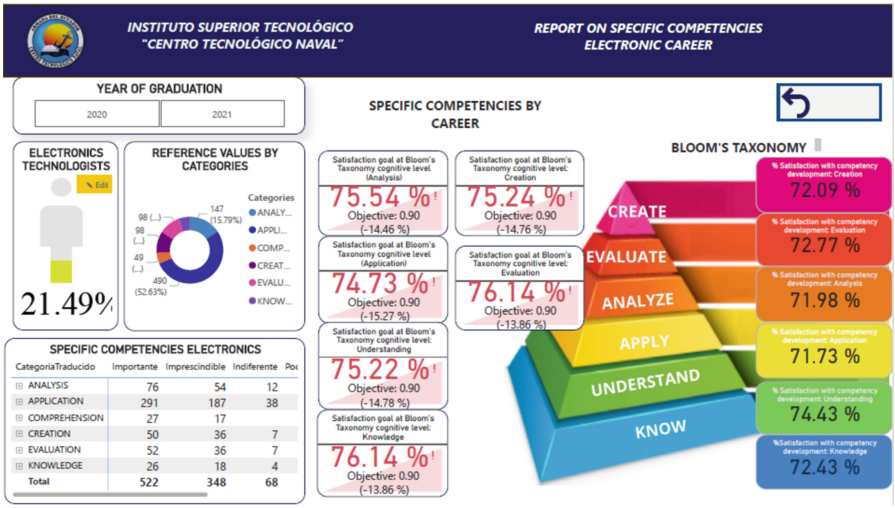

Fig. 4. Report specific Electronics career competencies.

5.4 Analysis of Results

From the results obtained from the dashboard containing the General Graduate Report through the automated process of relational data, we can visualize results where it is identified that out of the total graduates, 46.05% correspond to the Naval Sciences program, 21.93% to the Naval Mechanics program, 21.49% to the Electronics program, and 10.53% to the Electrical program.

Regarding the graduates from different provinces, we can identify that out of the total graduates, 70.61% come from the Guayas province, followed by 5.7% from the Pichincha province and 4.82% from the Los Ríos province.

We observed information on the naval divisions to which the graduates have been assigned and found that in the naval division named FRAMOR, there are 11 Technologists in Naval Sciences, 2 Technologists in Electricity, 3 Technologists in Electronics, and 14 Technologists in Naval Mechanics. Conversely, in the naval division named COGUAR, 13 Technologists in Naval Sciences, 2 Technologists in Electricity, and 1 Technologist in Electronics are employed. Additionally, in the naval division named ESDEAV, there are 3 Electrical Technologists, 9 Electronics Technologists, and 1 Technologist in Naval Mechanics.

The results show that, in the Naval Sciences program, 75.87% of the graduates are satisfied with the competencies acquired in the Professional Relationship category. For the Electricity program, this percentage is 84.72%, for Electronics it is 90.07%, and for Naval Mechanics it is 93.07%. Overall, this represents an 83.63% satisfaction rate with the generic competencies acquired by the entire group of graduates.

In the Curriculum Structure category, the results were as follows: 71.06% satisfaction for the Naval Sciences program, 82.05% for the Electricity program, 76.42% for the Electronics program, and 91.38% for the Naval Mechanics program. This reflects the satisfaction with the generic competencies acquired in this category by all graduates.

The results of specific competencies are analyzed individually for each program, as these competencies are tailored to each professional profile. They are categorized according to the verb used in the questions asked to the graduates, which allows them to be related to the cognitive levels established in Bloom's Taxonomy.

In the Electronics program, the results indicate that 72.43% of graduates are satisfied at Level 1 (Remember), 74.43% at Level 2 (Understand), 71.73% at Level 3 (Apply), 71.98% at Level 4 (Analyze), 72.77% at Level 5 (Evaluate), and 72.09% at Level 6 (Create) with respect to the development of cognitive thinking.

The reports generated by the graduate tracking dashboard provide agile and detailed management of graduate information through graphical visualizations, unlike previous reports that displayed data in extensive and confusing tables with percentages. These reports lacked certain important variables, which were included in the new business intelligence tool. In summary, the current process of managing and analyzing graduate data is confusing and slow compared to the business intelligence tool, which provides clear and immediate reports, facilitating data-driven decision-making. The reports generated by the dashboard have proven to be useful tools for analyzing relevant data about IST CETNAV graduates, significantly contributing to strategic decision-making in the educational field.

6 Discussion

The implementation of Business Intelligence (BI) solutions in higher education institutions has proven to be a crucial resource for optimizing academic management and strategic decision-making. In the case of Chiclayo, Mexico, a study at a university in the Lambayeque department employed Kimball's methodology to implement a BI solution. The results demonstrated that this tool not only significantly reduced report generation time but also increased report availability, thereby improving academic management efficiency. Similarly, our research at IST CETNAV revealed that the implementation of BI improved both graduate tracking and the quality of analyzed data.

In Ecuador, Viviana Malavé's study emphasized the importance of BI tools in institutional evaluation, particularly within the framework of accreditation processes. The creation of a Datamart and the implementation of ETL processes enabled efficient information management, demonstrating that BI tools are crucial for the continuous improvement of educational institutions. Our approach at IST CETNAV also benefited from ETL processes, which facilitated more effective data management.

Gary Torres's study at the State Polytechnic University of Carchi (UPEC) focused on the implementation of a BI platform for graduate tracking, utilizing Kimball's methodology to enhance data management. The results showed that the implemented BI solution allowed for the visualization of key indicators through a dashboard, significantly improving decision-making. Consistent with these findings, our research at IST CETNAV also demonstrated similar improvements in the visualization of key indicators, facilitating more informed and strategic decision-making.

In Colombia, David Fuentes proposed an adapted dimensional model that optimized data management in public higher education institutions, facilitating self-assessment and compliance with the accreditation standards of the National Accreditation Council

(CNA). Similarly, our research at IST CETNAV demonstrated how a BI solution can contribute to enhancing educational quality and the relevance of the offered programs.

Finally, Jarley Castillo's study in higher education institutions showed that the implementation of BI improves graduate information systems, optimizing both tracking and data management to support accreditation processes. Our approach at IST CETNAV confirms this trend, highlighting the importance of investing in training and fostering a data-driven organizational culture to maximize the benefits of BI.

In summary, the implementation of BI solutions in higher education institutions not only enhances academic management and institutional evaluation but also drives continuous improvement in educational quality. The results obtained at IST CETNAV reflect these benefits, underscoring Business Intelligence as an essential tool in the contemporary educational environment.

7 Conclusions

This study has demonstrated that the implementation of a Business Intelligence (BI) system for tracking graduates at the Instituto Superior Tecnológico "Centro Tecnológico Naval" not only optimizes the collection and analysis of data but also significantly enhances strategic decision-making. By utilizing the CRISP-DM methodology, a dimensional data model was developed that provides a clear and accessible visualization of information, facilitating the identification of trends and areas for improvement in the academic training of graduates.

For those looking to apply these findings to their own projects, a comprehensive set of tools and resources is provided. This includes a dimensional logical model adaptable to various educational contexts and an interactive dashboard for real-time data visualization. Additionally, key performance indicators aligned with the External Evaluation Model for Technical and Technological Institutes have been established, which can serve as a reference for the continuous improvement of academic programs. In summary, this study not only offers a theoretical and practical framework for implementing Business Intelligence in graduate tracking but also provides concrete tools that can be utilized by other institutions to optimize their data management and analysis processes.

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Strategies Based on Learning Styles for the Academic Improvement of the UISRAEL Students

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Abstract. This article discusses the significance of learning styles in academic improvement, particularly at the Israel Technological University (UISRAEL). It highlights the importance of understanding individual learning styles and how they impact academic success. The article presents various strategies for teaching and learning based on learning styles, emphasizing the need for a balanced approach that incorporates different modalities. It also explores the role of AI in test preparation and the importance of collaboration and feedback in the learning process. The article concludes by emphasizing the need for educators to consider the diverse learning styles of their students and to develop strategies that cater to these differences to ensure successful learning outcomes.

Keywords: learning styles · learning strategies · test ACRA

1 Introduction

In the realm of education, acknowledging students' diverse learning styles is crucial for enhancing their academic performance. Learning styles refer to individual preferences that influence how students absorb, process, and retain information. Designing educational strategies tailored to these styles can be key to the academic success of university students [1].

The diversity of learning styles in a university classroom necessitates flexible and personalized pedagogical approaches [2]. By considering students' individual preferences, an inclusive and effective learning environment is fostered. As stated by [3] aligning teaching with learning styles can significantly enhance understanding and retention of material.

According to previous studies, the following are some effective strategies for university students:

Initial Assessment: Utilize tools like the VARK Learning Styles Questionnaire [4] to identify students' preferences towards visual, auditory, reading/writing, and kinesthetic information.

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Diversification of Methods: Design activities that encompass different learning styles, such as visual presentations, group discussions, interactive readings, and guided practices [5].

Technological Adaptation: Incorporate interactive educational platforms like Kahoot! or multimedia resources tailored to various learning styles [6].

Peer Collaboration: Encourage diversified teamwork so students can learn from each other and develop social and cognitive skills [7].

Also, some common learning styles among university students, as supported by the provided sources, include:

Visual Learners: This students grasp information most effectively by using visual tools like maps, charts, diagrams, and graphs. They benefit from seeing relationships and ideas visually presented.

Auditory Learners: They prefer learning through listening and speaking. They understand information better when it is heard or spoken, such as through live lectures, podcasts, or group discussions.

Kinesthetic Learners: They are hands-on individuals who learn best through physical activities and experiences. They thrive when they can engage in practical, tactile learning.

Reading/Writing Learners: Reading/Writing learners excel when information is presented in written form. They prefer reading texts and writing notes to enhance their understanding.

These learning styles reflect how students process information and engage with educational material in distinct ways, highlighting the importance of considering individual preferences in teaching and learning environments.

Understanding student learning styles has significant implications for teaching and learning. By tailoring teaching methods to align with the diverse learning styles of students, educators can enhance the effectiveness of their instruction and improve student outcomes. Some key implications include:

Personalized Instruction: Recognizing and accommodating different learning styles allows educators to personalize instruction, making it more engaging and relevant for students.

Increased Engagement: Adapting teaching strategies to match student learning styles can increase student engagement and motivation, leading to a more positive learning experience.

Improved Retention: When teaching methods align with students' preferred learning styles, they are more likely to retain and comprehend the material effectively.

Enhanced Learning Outcomes: Tailoring teaching approaches to cater to diverse learning styles can lead to improved academic performance and overall learning outcomes for students.

Effective Communication: Understanding student learning styles enables educators to communicate information in ways that resonate best with each student, fostering better understanding and communication in the classroom.

Acknowledging and adapting to student learning styles can create a more inclusive and effective learning environment, ultimately benefiting both students and educators in achieving educational goals.

The study explores the significance of understanding individual learning styles for academic improvement at Israel Technological University (UISRAEL). It emphasizes the importance of adapting teaching methods to cater to diverse learning styles, promoting a balanced approach that incorporates various learning modalities. Additionally, the study discusses the potential role of AI in test preparation and highlights the importance of collaboration and feedback in enhancing the learning process.

The document aims to address how tailored educational strategies based on individual learning styles can enhance the academic performance of university students.

2 Learning Styles in Education

Examining learning styles is significant for both educators and learners and can influence a variety of perspectives and outcomes. Many argue that these effects are positive and lead to greater awareness and better performance. However, some questions remain about the most effective ways to make the most of current knowledge in this field [8].

Teachers. Scholars have shown a growing interest in learning styles and related assessment tools, teaching models, and learning methods. Because of the aim to customize and enhance student learning, it relies on various models promoted in professional magazines [9].

Others argue that teachers with a better understanding of learning styles will be more effective in teaching and assessment [10].

Despite the focus on learning styles, this topic deserves more attention in teachers' professional development. There is evidence that training can help teachers change their teaching styles, and planning tools can help teachers apply theoretical concepts in practice. However, initial training and mentoring are still needed to guide and support a better understanding of learning style theory and implementation of learning-based methods. Staff More research is needed to promote the development of effective staff development programmers. If teachers want to provide instruction that fits the needs of their students' learning styles, it is crucial that they possess the training and experience required to accomplish this [11].

Educators' convictions regarding themselves and their pupils greatly influence their instructional methods. Therefore, teachers' understanding of the structure of learning style has a significant impact on their understanding of differences in students' learning and teaching styles. Offering educators training and chances to gain insight into their personal learning styles allows them to better understand and meet the unique learning needs of each person they serve. Without this understanding, it is common for many teachers to maintain traditional methods favored by modern institutions as the best conditions for student success. In addition, teachers may unfairly view students as weaker or less able to learn in traditional ways [12].

Although some people say that "teaching style may be more important than the type of learning activity chosen," there are still many teaching strategies that teachers can use. To learn activities such as it is important to develop. Diverse environments and diverse models. Therefore, teachers must know how to differentiate instruction to meet these needs, give meaning to learning, and improve student success. Knowledge of learning styles will increase a teacher's confidence and ability to integrate different teaching styles to suit students' ability levels and learning preferences, while maintaining a high level of learning consistent with knowledge strengths. Additionally, research has shown that incorporating teaching strategies based on learning styles can help teachers create positive learning environments that demonstrate genuine interest in students and develop a love of learning [13].

Many educators believe that learning styles are not the ability or desire of each to put into practice the principles of the learning style in their daily life. Several prevalent designs that impact current methods are teacher-centered education, instructional model strategies, constructivist theory, experiential education, brain-based strategies, and differentiated instruction [14].

Students. Many studies have shown that different learning styles influence students' attitudes toward learning and academic performance. Although this explanation is inconsistent, it is a reasonable explanation for the different results that the same student can achieve with different teachers. Other factors that influence student achievement have been identified and researched, including stress, race, motivation, ability to self-regulate learning, economic status, and language skills, as well as the relationship between students and teachers. Despite the controversy surrounding the direct impact of learning styles on academic performance, it is important to know that learning styles influence students' interest in the learning experience. There appears to be strong evidence for perception. This affects academic performance and success [15].

Many studies have shown that different learning styles affect students' attitudes toward learning and school performance. Although this is not a consistent explanation, it is a plausible explanation for the varying outcomes that the same student may achieve with different instructors. Additional elements affecting student success have been recognized and studied, such as psychological pressure, cultural background, motivation, self-regulation in learning, financial situation, language abilities, and relationships with teachers [16].

Despite the ongoing debate about the direct impact of learning styles on academic performance it is important to know that learning styles affect students' interest in the learning experience. There appears to be a strong evidence on perception. This affects performance and success in school [17].

Motivation is a fundamental element of student learning and has a two-way effect on learning. While engagement is associated with learning, a lack of motivation has been recognized as a risk to academic achievement. Also, there seems to be a relationship between motivation and learning styles in the academic profession, a teaching practice that involves a variety of styles. The demands of the learning environment increase student motivation. Although it has been said that the focus of teachers and the education system on grades and standardized activities continues to stifle students' intrinsic desire to learn, it is also true that teachers instill a love of learning through their chosen teaching methods. The signal was also confirmed. Include it in your course. It is clear that the

motivation does not come from the superiority of the teacher. Emotional aspects identified include personal behavior and previous levels of achievement. However, it has been shown that students who are motivated by the joy of learning are actually "more likely to be effective long-term learners" than students who are motivated only by getting good grades. This lifelong drive and love of learning is essential to the development of all students. Lifelong learning, which involves the "continuous development and improvement" of knowledge and skills, requires students to learn how to learn. As a result, motivated, self-aware students learn more effectively in school and are more likely to learn in different situations than students who do not display these characteristics [18].

3 ACRA Test Results at UISRAEL

The article "Learning Strategies Used by Undergraduate Students at Israel Technological University" analyzes the learning strategies employed by undergraduate students at Israel Technological University and their relationship to academic success. The ACRA questionnaire was used to assess learning strategies, identifying acquisition, encoding, retrieval and support scales. The sample consisted of 743 students from all modes of undergraduate study at UISRAEL. The results, shown in Table 1, revealed that the scale most used by students in general is the retrieval scale, being predominant in Administration and Engineering courses. However, in Psychology and Education, coding and support scales are the most used. In spite of this, no significant correlation was found between academic averages and the use of the strategies. It is concluded that a broad and orderly teaching should be provided to ensure successful learning [19].

Table 1. Total results obtained for each strategy per career.

		Acquisition (%)	Coding (%)	Recovery (%)	Support (%)
ARTS AND HUMANITIES	PSICOLOGY	67,29	80,45	73,21	79,85
	INITIAL EDUCATION	68,10	78,63	74,56	80,42
	BASIC EDUCATION	68,23	79,52	74,32	79,69
	DIGITAL DESIGN	68,59	77,39	75,75	79,43
BUSINESS	BUSINESS ADMINISTRATION	69,11	69,87	83,46	80,22
	ACCOUNTING AND AUDITING	69,36	68,71	83,12	79,69
ENGINEERING	ELECTRONICS AND AUTOMATION	68,78	69,29	85,69	78,56
	TELECOMMUNICATIONS	69,66	67,12	86,98	79,23
	INFORMATION SYSTEMS	68,42	66,50	85,42	78,61
	COMPUTING	67,84	66,44	85,38	77,6

4 Results

Based on previous studies and the results obtained at Uisrael, there are some strategies that can be applied on each of the areas for the academic improvement:

4.1 Arts and Humanities

In general, humanities courses will focus primarily on literature, in-depth analysis of texts, academic essays, and expository writing. The emphasis on generating and analyzing ideas helps humanities students graduate with a strong foundation in research, writing, and critical thinking rather than disciplinary knowledge. This of course depends on the specific subject of your degree and the program chosen. However, it is better to choose a humanities degree with the goal of pursuing a career that requires a deep understanding of people and society or communication, critical thinking, and organizational skills [20].

Here there are some strategies that Arts and Humanities students can use: (1) When considering the diverse disciplines that embody the humanities, it's paramount to tailor your study methods to address the unique challenges they present. Unlike the empirical nature of the sciences, arts and humanities subjects are steeped in interpretation, critical analysis, and an appreciation of the context. Successful test preparation in these fields hinges on creating study strategies that resonate with the expansive and subjective material at hand [21]. (2) Understand the Landscape of Humanities Exams. Exam questions, often differ significantly from scientific and technical subjects. They demand a grasp not just of facts, but also the ability to weave those facts into a coherent narrative. The evaluation of students' understanding in humanities subjects goes beyond mere recollection, emphasizing the synthesis of ideas and the formulation of well-supported arguments. As you prepare for humanities exams, consider not only what you're learning but how it's applicable in a broader cultural and historical tapestry [22]. (3) Strategies to Study Efficiently for Humanities: To study efficiently in the humanities, active engagement with the material is key. Instead of rote memorization, engage in activities that foster critical thinking and a deeper connection with the content: Discuss reading materials in study groups to gain multiple perspectives, write summaries of chapters or articles to distill their essence, create concept maps linking themes, characters, and events in literature or art history, apply theoretical frameworks to case studies or historical events to solidify understanding. Cultivating these habits will not only prepare you for your exams but will also equip you with skills applicable in any sector that values analytical thinking and effective communication [23].

Also, (4) The Role of AI in Test Preparation for the Arts: with the advent of AI-powered learning tools, students are finding innovative assistance in their study routines. When used ethically and appropriately, AI can offer a supplementary layer of support [24]. (5) Master Essay Questions: humanities exams often feature essay questions to assess critical thinking. Start by outlining your essay to organize your thoughts. Support arguments with evidence from your studies. Practice writing essays under timed conditions similar to exam settings. This tripartite strategy combined with regular feedback from educators can significantly bolster your essay-writing capabilities [25]. (6) Comprehension Over Memorization: In the humanities, understanding concepts trumps

memorizing details. Instead of cramming the night before an exam, integrate regular study sessions that allow for contemplation and connection-building. When studying, always ask "why" to go beyond superficial knowledge and delve into the deeper significance of the material [26]. (7) The Synergy of Traditional and Digital Resources: While textbooks and lectures remain foundational, supplementing them with digital sources can offer a new dimension to your learning. From podcasts discussing historical events to online art galleries, make the most of the wealth of resources available to deepen your appreciation and understanding of the humanities [27]. (8) Collaborate and Share Insights: Lastly, collaboration can be incredibly beneficial. Share your insights with classmates and seek out different viewpoints, which will inevitably enrich your own perspectives and interpretations. By exchanging interpretations and critiques, you create a dynamic learning community that thrives on diverse thought [28–30].

4.2 Administration

For many students, studying business can be a difficult subject. Nonetheless, with appropriate strategies implemented, succeeding in business studies can be a feasible result.

Here are various strategies and recommendations to assist students in maximizing their business studies classes: (1) Gain insight into business principles: business studies cover a wide array of concepts and abilities. To achieve success in business, it is essential to grasp data interpretation, financial analysis, marketing tactics, and economic concepts. Gaining this comprehension necessitates a dedication to education. Creating a study strategy that suits your needs is essential. The initial step to mastering business studies is to understand the fundamental concepts. This may involve studying textbooks, participating in lectures or seminars, or enrolling in online courses [31]. (2) Effectively research subjects: conducting keyword research is a crucial step in researching subjects effectively, as it enables you to create a list of pertinent search terms and phrases to concentrate your efforts. When assessing sources for reliability, it's vital to take into account the author's credentials, the publisher or website, the publication date, and any reviews linked to the source. After gathering a variety of information regarding your subject, it is crucial to efficiently arrange the data to recognize key concepts and themes. Structuring your research based on the main points of the topic aids in comprehending the material and discovering significant relationships. Using a mind map or concept map can assist in organizing your research by visualizing the links among different ideas and points. Keeping a record of your research process will help you remain organized and monitor the information you have accumulated [32].

Likewise, (3) Keyword Research: is an essential part of researching any topic effectively. It involves analyzing trends in order to identify relevant topics, discover what people are searching for and track data associated with those searches. This information can then be used to craft content that is most likely to resonate with the target audience and get them to take action [32]. (4) Source Trustworthiness: Considering the trustworthiness of sources is crucial for effective topic research. When examining bias and integrating data, it is crucial to guarantee that the sources consulted are dependable and credible. This can be achieved by evaluating the source's precision, credibility, impartiality, and timeliness. Verifying citations and references can additionally assist in

affirming a source's credibility. Furthermore, it is essential to ensure that all information included in the research is current and pertinent to the subject being studied [33]. (5) Information Organization: is a crucial phase in the research procedure. To effectively investigate a subject, it is crucial to ensure that collected information is arranged in a manner that facilitates easy access and comprehension. To achieve this, it is crucial to develop outlines and implement note-taking methods like summarizing or emphasizing main ideas [34]. (6) Employ Study Plans: An effective study plan necessitates assessing goals and exercising self-discipline. It serves as a framework for establishing a setting that promotes learning. A personalized study plan must be created for the individual, incorporating these elements: setting achievable objectives, creating a schedule, and locating resources [33]. (7) Utilizing Technology: contemporary technology has transformed how we educate and learn. Business students can now utilize digital collaboration tools to engage with one another, share knowledge, and build significant connections that can assist them in reaching their objectives. Utilizing virtual seminars enables business students to tap into extensive knowledge from leading experts in the industry without needing to step outside their home. Through the use of digital collaboration platforms like online discussion boards or chat rooms, they can seamlessly engage with others who possess similar interests or who have already effectively dealt with the same subjects they are exploring [32].

Similarly, (8) Focusing on Tasks. Utilizing technology can effectively enhance your study routines and assist you in becoming more organized. Nonetheless, it is crucial to prioritize assignments while studying, to guarantee that the most significant tasks are accomplished first. Focusing on tasks can assist you in utilizing your time more effectively and achieving objectives faster [35]. (9) Maintain Organization: being organized is a crucial element of excelling in business studies. Creating efficient time management and goal-setting techniques can assist you in remaining focused and ensuring that you allocate sufficient time and effort to your academic work. To start, it's essential to establish a timetable that details the time you will dedicate to studying each day or week. Furthermore, think about how you can manage other responsibilities such as work and social interactions while ensuring you have enough time for studying. It's crucial to have a realistic viewpoint on what you can achieve in a specific timeframe and motivate yourself to adhere to the strategy. Establishing objectives is another excellent method to remain organized while preparing for business studies. Divide extensive tasks into smaller sections to make them more manageable and easier to finish on time. Furthermore, ensure your goals are quantifiable to monitor progress consistently [34]. (10) Master Exam Tactics: preparing for exams is a crucial aspect of excelling in business studies. Possessing a thorough plan and appropriate resources can assist students in achieving their targeted academic objectives. One method for students to get ready for exams is to develop a study schedule and adhere to it. This ought to encompass designating particular time slots for every subject that requires studying. Dividing the material into smaller parts can simplify the process, along with establishing mini-goals and treating yourself after reaching each milestone [32]. (11) Enhance Reading Understanding: involves examining texts and exercising memory. To successfully achieve this, five essential strategies can be integrated into the learning process: analyzing texts, pinpointing the main idea of a passage, exploring the structure and organization of the

text, recognizing significant connections between ideas, practicing recall, summarizing what has been read either in writing or verbally, explaining the relationship between two different ideas, and discussing key themes present in the text [31]. (12) Cultivate Problem-Solving Abilities: crafting impactful papers is crucial for achievement in business studies. It is the ability that enables students to communicate their ideas and thoughts clearly, succinctly, and precisely. Enhancing problem-solving abilities is the subsequent phase in achieving proficiency in business studies. Problem-solving abilities necessitate that a student can recognize a problem and subsequently utilize critical thinking and analytical information to find a resolution. A method to enhance problem solving abilities is by employing creative thinking strategies like brainstorming and mind mapping. Brainstorming consists of generating a list of possible solutions for a problem initially without critiquing or assessing them. This encourages the creation of ideas that might not have been thought of before. Mind mapping involves creating diagrams or charts to illustrate the connections between aspects of the issue, enabling deeper investigation of potential solutions [34].

As well, (13) Collaborate with Study Groups: group studying can be advantageous when executed properly. Organizing your group effectively is the initial step toward attaining success. When forming a study group, take into account the requirements and objectives of every participant. Establishing a cooperative atmosphere is essential so that all individuals feel at ease sharing their questions and ideas. Motivating members to engage equally will assist in maintaining the learning process effectively and will also aid in managing time. Establishing clear guidelines for the group's operation is equally essential. Establishing achievable objectives, like finishing a specific amount of content by a designated deadline, and allocating responsibilities to each participant to evenly distribute tasks can assist in making sure that everyone is responsible for their contribution to the team's success [33]. (14) Control Stress Levels: handling the pressure of juggling academics, employment, and social engagements can be daunting. Efficient time management and coping techniques are crucial resources for handling stress levels. It is crucial to acknowledge when you feel overwhelmed and to take suitable actions to lower your stress levels. A useful method for handling stress is to establish a daily plan that incorporates breaks. Allocating sufficient time for studying, completing tasks, and enjoying leisure is essential for managing stress effectively. Regularly pausing during the day can refresh your mind and enhance creativity when you resume studying. Moreover, creating a proper sleep pattern can assist in managing stress levels since sufficient rest aids your body and mind in recuperating from daily activities. Practicing mindfulness techniques like deep breathing or meditation can also be beneficial as they help you remain in the present rather than stressing about future or past occurrences [35–39].

4.3 Engineering

First, it is important to determine why you have difficulty with a subject or problem: mathematics, basics, and try to understand the qualitative picture, look at the final result of the derivative, usually a simple mathematical expression. Let's see which term is in the numerator and which term is in the denominator, what is the exponent? Draw these equations in different ways, and complex application.

In engineering, we must consider engineering practice to be design: solving previously unsolved problems, and solving problems in new ways, using new technologies. In addition, managing creativity is difficult but not impossible (learning to think), ambiguity: in many cases there is no clear (or even desirable) optimal solution, and developing a "tolerance for ambiguity".

Some techniques that can be used are: (1) Read the material three times: Reading the entire chapter is like reading a novel. Don't worry about the details, try to look at the big picture. Try to do this before the relevant lecture [40]. (2) Study each part of the chapter. Use highlighter sparingly. Copy the examples [41]. (3) Read notes from the chapter. If you don't like the way the text covers the topic, find another textbook (in the library) that does a better job [40]. (4) Keep track of your weekly homework [41]. (5) Use a special board and notepad for drafting and additional calculations [42]. (6) Solve problems on your own as much as possible (but learn from others) [40]. (7) Start by summarizing the problem (classify the problem: Is the problem a form of general thinking, a simple mathematical operation, or a design problem? What is data? What should be calculated? [41]. (8) What issue should you raise? What are the hypotheses? What are the related formulas? [43]. (9) Make a rough sketch (ignore the details, and visualize where the problem will take you) [44]. (10) Step back and pay attention to the details: Can you make fewer assumptions? Are your calculations perfect?, those are questions that you need to ask [40]. (11) Check your answer: units, is the answer reasonable?, checking boundary conditions, checking the symmetry of the answer [42]. (12) Do not use the answer sheet [41]. (13) Discuss and discuss the issue with a conscientious classmate (be open to different techniques, question logic, be aware of pitfalls) [45]. (14) You end when you are sure of your answer [46]. (15) Sit where you can hear the discussion and read the board [45]. (16) Take notes (not only mathematics but also logic, every 2–3 weeks copy your notes into a separate notebook) [41]. (17) If you have to miss class, borrow notes from 2–3 other students, write them in your notebook, then ask questions about what you don't understand [45]. (18) Do not cram right before the exam [47]. (19) Good night [43]. (20) Copy (re)copy your readings and lectures. Your notes will become shorter because you remember more and find things clearer [47].

Implementing strategies that align with diverse learning styles can be beneficial, but it also comes with several challenges. Here are some of the key challenges identified: time constraints, financial resources, teacher training, classroom management, assessment and evaluation, technology integration, student adaptability, learning preferences, curriculum Design, collaboration and communication.

While implementing strategies aligned with learning styles offers significant benefits, it requires careful planning, resources, and continuous adaptation. Overcoming these challenges involves commitment from educators, institutions, and policymakers to ensure that diverse learning needs are effectively met.

5 Conclusions

The article emphasizes the importance of understanding and catering to diverse learning styles to improve academic outcomes at the Israel Technological University (UISRAEL). It highlights the need for educators to employ a balanced approach that incorporates various teaching strategies to accommodate the different learning preferences of students.

The article highlights the importance of nurturing positive student views of their school and their roles as learners, as this not only improves the classroom atmosphere but also affects their academic success. The results of the ACRA questionnaire administered at UISRAEL revealed that the retrieval scale is the most used learning strategy by students in general, particularly in Administration and Engineering courses. However, in Psychology and Education, coding and support scales are the most prevalent. Despite these findings, no significant correlation was found between academic averages and the use of specific strategies. To address these findings, the article proposes strategies for academic improvement in different areas. For Arts and Humanities, it suggests tailoring study techniques to the unique challenges of these disciplines, understanding the landscape of humanities exams, utilizing traditional and digital resources synergistically, and collaborating with peers to share insights. For Business Administration, it recommends developing an understanding of core concepts, researching topics effectively, utilizing study plans, making use of technology, prioritizing tasks, staying organized, mastering exam strategies, improving reading comprehension, developing problem-solving skills, working with study groups, and managing stress levels. The article concludes by emphasizing the need for a broad and orderly teaching approach to ensure successful learning outcomes at UISRAEL. By understanding and catering to diverse learning styles, educators can create a more inclusive and effective learning environment that fosters academic success for all students.

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Gamified Application for the Reinforcement of Mathematical Skills in Elementary Education

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Abstract. In response to the consistently low performance in mathematics among elementary students in Chile, a mobile application using gamification techniques was developed to enhance student engagement and academic achievement. This paper explores the implementation of this gamified app, designed to make mathematical learning both interactive and enjoyable. Leveraging elements typical of gaming, such as points and levels, the app aims to increase intrinsic motivation and participation within the classroom setting. The intervention included a group of students who used the app over a specified period, allowing for a pre and post evaluation of their mathematical skills and interest levels. Results showed an increase in mathematical performance and a modest increase on a Likert scale in students' interest towards mathematics. These findings suggest that gamification can serve as an educational tool to enhance learning and student engagement in mathematics.

Keywords: Gamification · Math Skills · Math interest

1 Introduction

Learning is influenced by a series of complex factors, such as motivation, differences in cognitive levels, disciplinary preparation, the teacher's methodology, and the student's attitude [1]. Mathematics is considered a fundamental subject in the educational system due to its importance for intellectual development, especially in fostering critical thinking and logic. However, despite its relevance, teaching mathematics can generate both passion and disaffection among students due to the difficulties it presents. These difficulties lie in the pedagogical aspect, inappropriate teaching methods, and socio-affective situations from both the teacher's and the student's side [2]. Concern about low performance in mathematics is a global phenomenon attributed to various causes, including monotonous teaching that leads to frustration and failure. In Chile, studies conducted by the National System for the Measurement of the Quality of Education

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(SIMCE) have identified several factors associated with performance in mathematics, such as motivation, enhancing students' capabilities, parental involvement, and the educational institution itself. [3]. The methodology of teaching mathematics is a crucial aspect to address low performance. The EURYDICE project (2011) [4] highlights the importance of effective pedagogical approaches and underscores the need for monitoring student performance. Additionally, the significance of the student's intrinsic motivation for achieving academic success, along with study habits, is recognized [5]. Despite efforts to improve the quality of education, the learning outcomes in mathematics in Chile remain concerning [6]. The integration of Information and Communication Technologies (ICT) into education has transformed traditional teaching models, allowing for more meaningful and constructivist learning [7]. ICT offers new opportunities for teaching mathematics by facilitating knowledge construction and promoting skills such as problem-solving and collaborative work [8]. In this context, gamification emerges as a promising strategy to enhance the teaching of mathematics by integrating game design elements and mechanics into the learning process. Gamification, combined with ICT, aims to motivate students and promote their active participation in the classroom [9]. This strategy has proven effective in promoting meaningful learning and developing cognitive skills [10]. This article proposes a gamification solution based on the implementation of a mobile application that allows teachers to reinforce basic mathematics skills in a didactic, motivating, and adaptable way to the student's pace. This is supported by the principles of gamification and how its application can impact the motivation of young people by mixing didactic methods with attributes typical of video games [7]. The application will be implemented in a group of students who will be assessed before and after using the application to measure improvements in skills and also a perception survey will be conducted to measure motivational aspects.

2 Related Works

2.1 Context

Mathematics stands as one of the most important subjects in the school environment, as it is a fundamental pillar for the development of logic and critical thinking [1]. Despite its relevance both in personal growth and in the academic sphere, the teaching of this discipline faces challenges that have led to poor outcomes in assessments. The low performance in the subject of mathematics in Chile presents a tangible problem, supported by national assessments such as SIMCE [11]) and international tests like the PISA exam. In the latest assessment conducted by the Programme for International Student Assessment (PISA) in 2018, which involved 79 countries, including Chile, significant results were obtained. That year, the assessment was conducted by 7,621 students from 257 randomly selected establishments, covering municipal schools, subsidized private schools, and private institutions across the country. The results revealed that Chile ranks 59th in the subject of mathematics, with an average of 417

points, again below the OECD average of 500 points for mathematics. Along with 23 other countries, including France, New Zealand, and the United States, no statistically significant differences were observed between the results of 2015 and 2018 in the domains of Reading, Mathematics, and Science. In Chile, data from the SIMCE evaluation, which measures the level of students in the 4th year of primary education and the 2nd year of secondary education, are available. The data refer to students' performance in the mathematics test. The performance of 4th-grade students has shown a downward trend since 2016. However, the factors that could be contributing to this problematic situation are diverse, and addressing them all simultaneously is complex as indicated by Münzenmayer et al. [1], where basic and secondary education students were asked about what they believed could be the causes of low performance in the subject of mathematics. The responses vary, some pointing to the education system, others to personal situations or even to the teachers and the nature of the subject itself, but they show a coherence in the responses of basic and secondary education students, except in one, the understanding of the material, which is an activity that requires more effort in basic education students, according to the responses given.

2.2 Gamification

The concept of gamification, although relatively new, does not refer to an unknown practice in the educational field. It is understood as the implementation of elements typical of video games in areas that may or may not be related to them [12]. The main objective is to facilitate learning through activities that maintain the interest of the participants. When discussing gamification in educational environments, game techniques such as mechanics, dynamics, and aesthetics are incorporated, with a digitally renewed focus, proving effective in motivating students while they learn. Among the game mechanics sought to be implemented in other areas are challenges, unlocking phases, badges, points, levels, or ranking positions. Although several studies have implemented gamification in classrooms with mostly positive results, it is not a miraculous solution. Certain conditions must be met to achieve the expected results. According to García et al. [8], gamification can significantly affect academic performance as long as the applications used are designed under appropriate cognitive parameters, are based on gamified elements, and the teacher accompanies this process. Gamification, as a motivational methodological strategy, plays a crucial role in the teaching-learning process by allowing the teacher to capture the attention and encourage students to develop skills and abilities that facilitate the assimilation of knowledge in a significant way. The implementation of information technologies and gamification constitutes an integral part of the solution proposed in the document. However, it is crucial to highlight that this implementation will not generate the expected results without the active collaboration of teachers. It is imperative that teachers abandon the traditional paradigm of being mere sources of knowledge and take on a more active role as participants in the educational process. As Bahamonde [12] points out, this change must begin with

the teachers, who must become aware of their new role in the development of learning. Additionally, the implementation of game mechanics to reinforce learning cannot be achieved with the vision of the omniscient teacher. The current demands of the technological era force teachers to innovate constantly, making it essential to incorporate strategies that adequately respond to formative processes and promote collaboration, criticality, and knowledge [8]. It is crucial to highlight that education, especially in the field of mathematics, is not just about the transmission of information. Education must adapt to changes and innovations to contribute significantly to the development and construction of knowledge [7]. Research conducted at an institution in Medellín suggests that the traditional methodology for teaching mathematical operations and solving problems has not been the most suitable. These concepts are learned as a set of memorized data, limiting the management of knowledge and hindering the applicability of the concepts in the everyday context of the student [13]. This highlights the challenges that teachers face when dealing with digital natives. Gamification in the teaching of mathematics has proven to be an effective tool for improving both motivation and academic performance of students. Through various studies, it has been observed that the integration of game mechanics, such as points, badges, and leaderboards, in educational settings can foster greater engagement and better retention of mathematical content [14]. However, the effective implementation of these gamified strategies requires careful consideration of the different learning styles of students, as well as the adaptability of activities to cater to diverse capabilities and skill levels. For example, adaptive and collaborative approaches in gamification have proven to be particularly beneficial in studies conducted in primary education contexts [15], highlighting the need to personalize challenges to maximize individual learning. The role of technology in educational gamification is indispensable, as it provides the platforms and tools necessary to implement these pedagogical strategies efficiently and attractively. Educational apps developed in collaboration between researchers and entertainment companies have proven effective in early mathematics learning and in other informal contexts such as math walks [16]. These technologies not only allow for a broader and more accessible implementation of gamification, but also offer opportunities to collect real-time data on student progress, which can help continuously adjust and improve educational activities. Nonetheless, the challenge remains to ensure that content design is pedagogically solid and that technological platforms are robust and secure for educational use [17]. Despite the evident benefits, the implementation of gamification in mathematical education is not without challenges. One of the main issues is the lack of adequate training for educators, who need a deep understanding of how to effectively use these strategies to facilitate learning [18]. Additionally, there is a need to ensure that gamification does not displace traditional pedagogical fundamentals, but rather complements them. Therefore, while gamification offers great potential to enrich the teaching of mathematics, its success depends on careful and considered implementation that addresses these challenges comprehensively

3 Proposed System

3.1 Design

In order to generate a technical design of the mobile application, the following figures will present the most relevant aspects and classes of the application. Figure 1 shows the relevant classes within the system. In the center, we find the user class, which can generate game sessions through which it obtains points. These points will serve the user to acquire new avatars. The 'User' class stores the information of each student who logs in with a valid email and password. Each user instance is related to a 'User Record' instance, in which the relevant data of the player within the application is stored. The user can also access several instances of the 'Avatar' class, which represents a customization element obtainable through the app store. Finally, a user can access several instances of the 'Game' class, where the game flow is managed by the 'Game Controller' class, in which game points are earned. Each instance of the 'Game' class also includes 15 instances of the 'Question' class which must be answered by the user. Within the physical view, the physical assignment of the system components in the execution environment is shown in order to demonstrate how the software is distributed on the hardware, through a deployment diagram of the application (see Fig. 2). It starts with the user, who accesses the application from their mobile device. The application uses React Native functionalities to render the views of the application. Once the application is launched, it connects to Firebase services to authenticate the user and grant access to their account, as well as allowing the game controller to access the questions once the user starts a game.

In the package diagram located in Fig. 3, we find the structure of folders and files, along with the way they communicate with each other for the application's operation. The application has a model-view-controller architecture, with both packages connected alongside the database connection made by the controller.

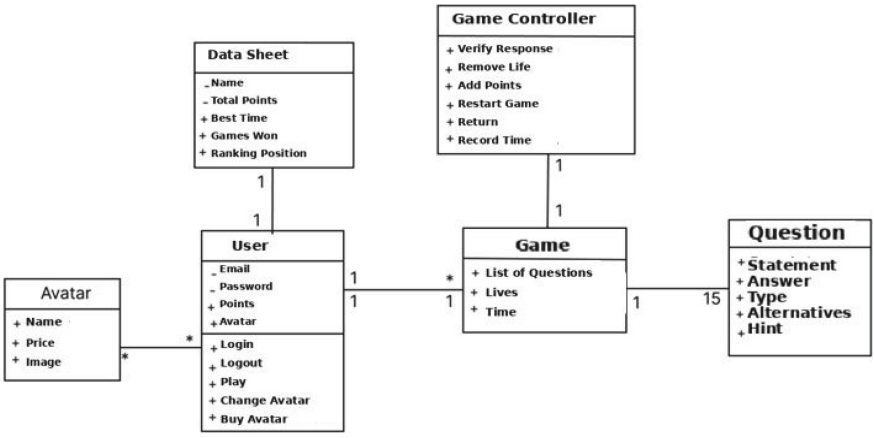

Fig. 1. Class Diagram.

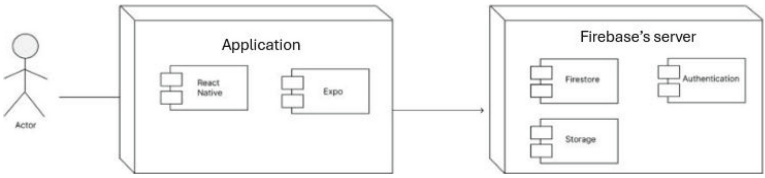

Fig. 2. Deployment Diagram.

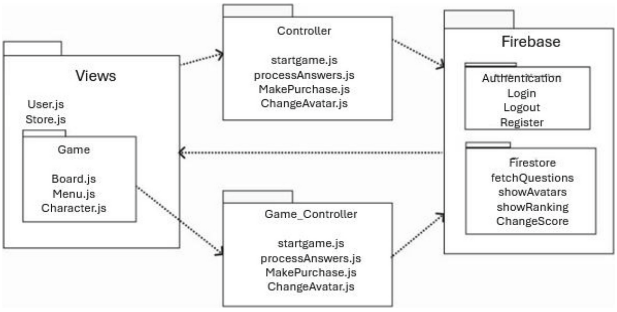

Fig. 3. Package Diagram.

In this view, the scenarios generated by the interaction between the user and the system are displayed with the aim of understanding the system from the user's perspective. Figure 4 shows the actions that the user can perform once the application has been started, assuming that the user logs in with the correct credentials. Specifically, it shows the actions of starting a game and what actions can be taken within these. The project implements elements such as points, rewards, challenges, levels, and rankings to encourage student participation and learning, allowing personalized progress according to each student's pace and evaluating its impact on mathematical skills and motivation. This development is essential to ensure that gamification functionalities are implemented effectively, supporting both student motivation and academic performance in various educational contexts. Specifically, it shows the actions of starting a game and what actions can be taken within these. Once the user has logged into the application with their credentials, they have the option to start a game. While in the game, the user can access the pause menu, from which they can restart the game, return to it, or exit to the main menu. If they choose to continue with the game, they have the option to answer the questions presented in it. If they answer a question correctly, they will accumulate game points which they will receive at the end of the game, otherwise, they will lose one of the three lives they have per game.

3.2 Development

To track each student's activity individually, it is required that each student creates an account to access the application. This requirement establishes the

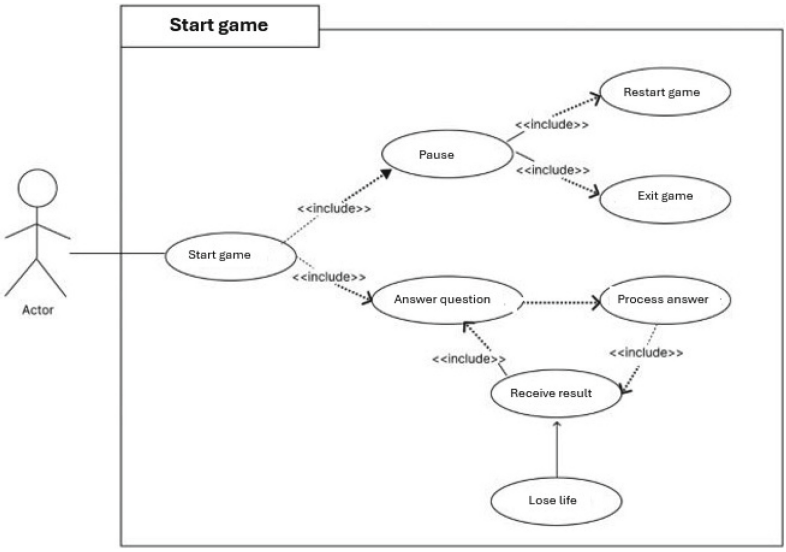

Fig. 4. Use Case Diagram.

foundation for a personalized experience and effective monitoring of each student's individual progress. The Login and registration views are shown in Fig. 5.

The student will be greeted with the home screen, where they can directly start a game or navigate to any of the other available views via the modal, also considering the option to log out. From this view, the number of points the user has can also be seen, as shown in Fig. 6. Points are earned by winning games and can be used both to purchase new avatars and to move up in the rankings.

During the game, the student will need to solve 15 puzzles, which will require basic mathematical knowledge and mental agility to be solved as quickly as possible. The player has 3 lives to overcome the challenge; if they lose all 3, they will have to start the challenge over, losing any rewards they had accumulated up to that point. The views associated with the game development are shown in Fig. 7. The player can also restart the challenge or quit the game whenever they wish; however, this also means losing the rewards. Figure 8 indicates the three types of questions that can appear to the player per game, the first being oriented towards knowledge and the other two towards basic mathematical skills.

Within the user view, accessible from the modal located in the upper left corner, the user can view their game statistics, the avatars they have obtained, and their position in the player ranking as shown in Fig. 9. In Fig. 10, which corresponds to the store view, the player will be able to redeem the points they have earned in the games for avatars that can be selected from the user view. Once the activities associated with development were completed, a portable mobile application was obtained that, through a link, would be available for download by students in the following phases.

Fig. 5. Mobile App Login.

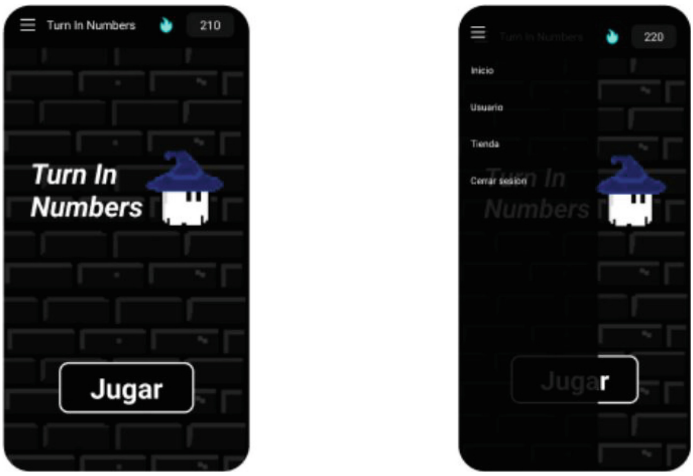

Fig. 6. Mobile App Main View.

3.3 Data Gathering

Meetings were held with the school board and mathematics teachers at Boston College in Maipú to agree on permissions and deadlines for using the application. Due to the limitations on working with students, it was decided to select a single group of 8th grade A students from Boston College in Maipú, consisting of 15 students, to participate in the study of the gamified application. This group was evaluated before and after using the application, allowing for a comparison of their own results in terms of academic performance and interest levels, thus ensuring a controlled and relevant measurement of the impact of gamification

Fig. 7. Game Session View.

Fig. 8. Mobile App Questions.

on their learning without other elements that could influence the results during the sample period.

During the implementation of the project, the 8th grade A students used the application as an activity during 10-minute intervals, which, on average, encompasses a total of 3 game sessions. This dynamic was carried out three times a week, coinciding with the instances when the mathematics subject was taught. Considering the 24 d available for implementation between September and October, and the average number of game sessions a student could participate in, a total value of 80 average game sessions per student during the entire implementation phase is established. Once the tasks of this phase are completed, the students are ready to retake the evaluations and compare the results with the data already obtained.

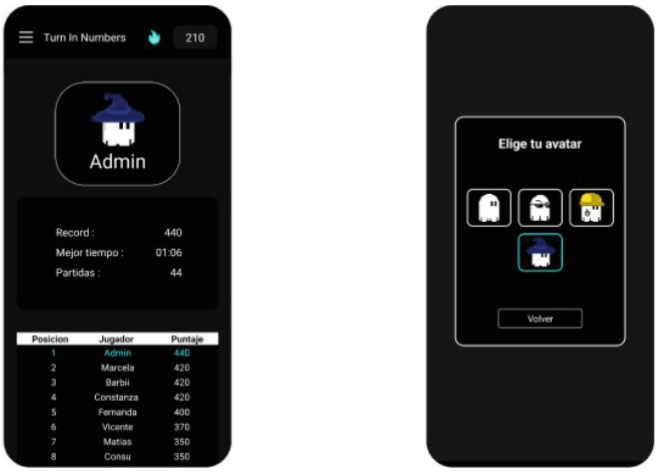

Fig. 9. User Views.

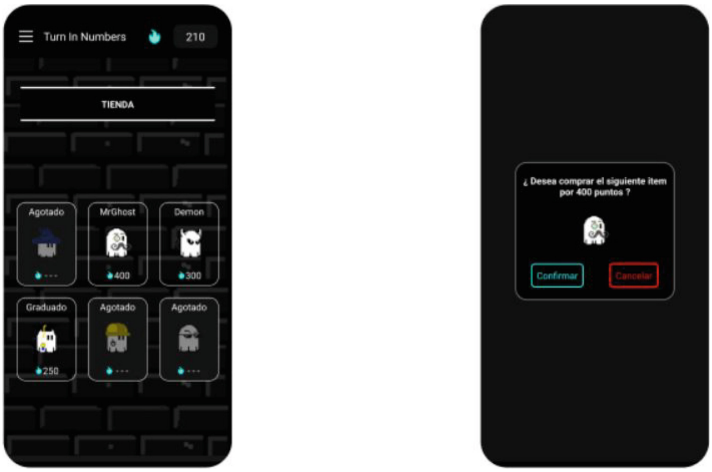

Fig. 10. Store View.

4 Results

After the two evaluations were conducted, the results were recorded and compared between the evaluations. Figure 11 shows the grades obtained by the students in both evaluations. Although the improvement in grades is not uniform for all students, an increase in grades can be observed, reflecting the positive impact of the application, given that there were no other different elements in the group of students during the study period. Specifically, the overall average grade increased from 3.8 in Evaluation 1 to 4.1 in Evaluation 2, which demonstrates

an improvement in the students' understanding and academic performance after using the gamified tool.

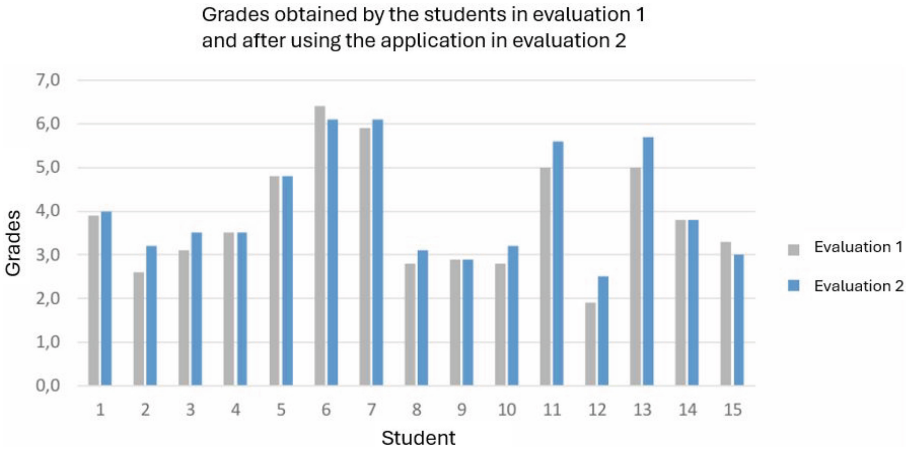

Fig. 11. Grades obtained by the students before and after use of application.

Figure 12 represents the number of questions answered correctly, showing an increase in the median, which rises from 6 correct answers in Evaluation 1 to 8 correct answers in Evaluation 2. Additionally, the range of correct answers narrows, indicating that more students were able to improve their performance by answering between 6 and 10 questions correctly in the second evaluation, compared to a broader and lower range in the first evaluation.

Regarding the data obtained from the interest survey, there was an observed increase in students' interest towards the subject, along with an increase in their perception of their capabilities and the importance of mathematics in life. Furthermore, the use of the application in the classroom could influence the students' perception of the educational system, as after the implementation, the average number of students who considered the educational system outdated increased. Figure 13 represents the results of the motivation survey conducted with the students, both initially to compare with a second application of the same survey after using the application.

While there is an improvement in the various aspects surveyed, the students' preferences do not change drastically. The average score of the survey for the first evaluation was 2.1, while for the second survey process it only increased to 3, indicating that a technological implementation by itself is not sufficient to generate significant motivational changes.

A possible explanation for these limitations could be the brevity of the implementation period and the limited daily exposure to the application. Students only interacted with the application for brief intervals within the classroom context, which may not have been sufficient to effect deeper, long-term changes in

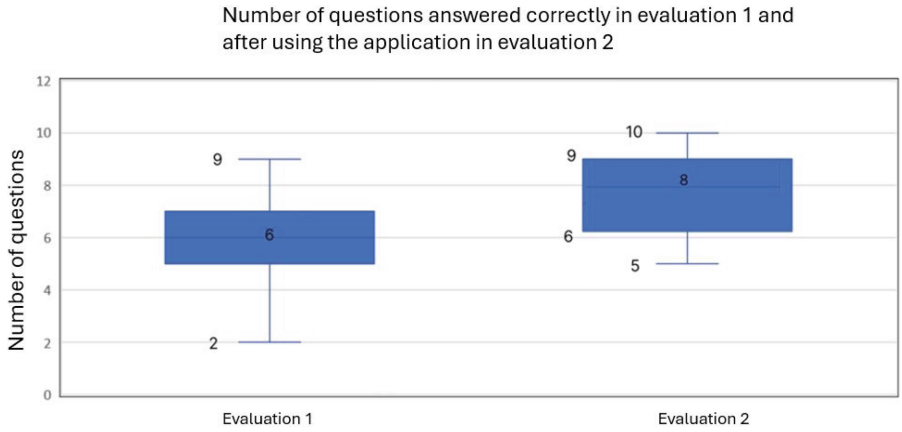

Fig. 12. Number of questions answered correctly before and after use of application.

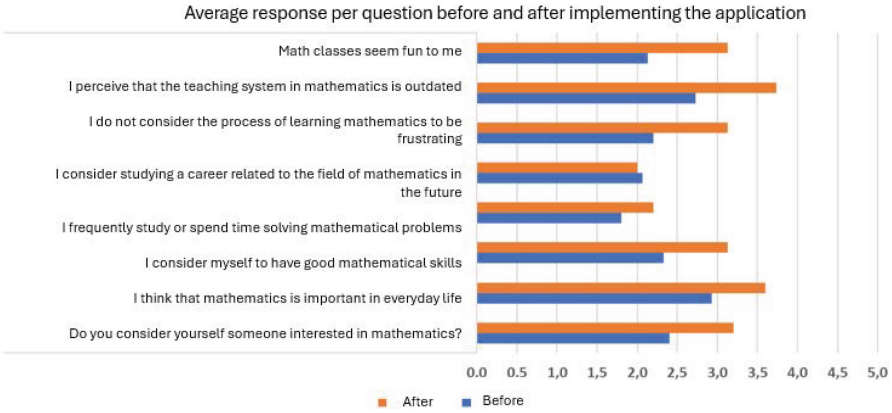

Fig. 13. Survey Interest Results

their attitudes towards mathematics. Additionally, it is possible that the selected student sample already had predispositions towards the subject that could not be significantly altered in the short term.

While gamification presents itself as an interesting tool in the classroom, the results show an improvement in grades but a low appreciation towards the study of mathematics, suggesting the need to expand these studies to other situations, other subjects, types of teaching conducted in the classroom, different cultures, etc. In cultures with high power distance, such as Japan, where the authority of the teacher is highly respected, gamification strategies might require adjustments to respect this hierarchy. In [19] emphasize the need to adapt educational technologies to local cultural values to achieve successful acceptance. Additionally, gamification has proven effective in various subjects. For example, [20] found improvements in motivation and performance in science and technology courses

in higher education, while [21] evidenced its effectiveness in disciplines such as biology and history, suggesting a broad potential for generalization. Therefore, further research is needed in specific educational communities to allow for comparison of results across different educational and cultural contexts

5 Conclusions

Among the results of the project, the improvement in the academic performance of the students stands out, which is reflected in the increase in average grades and the number of correct answers in post-implementation mathematics assessments. These results are evidence of the effectiveness of gamification as a tool to enhance mathematical skills and knowledge in an educational context. The increase in participation and performance suggests that the game elements incorporated into the application helped the students engage more deeply with the content and better understand the mathematical concepts presented.

However, although there was a general increase in positive perception towards the subject, it was more modest than expected. Interest was measured through pre- and post-implementation surveys, where aspects such as the perception of the importance of mathematics and individual interest in the subject were evaluated. The results indicated that, while the application had a positive impact, it was not sufficient to meet the expectations for a transformative change in students' attitudes towards mathematics.

6 Future Works

For future work dedicated to this area, other socioeconomic segments could be considered to measure whether the impact of gamification is the same in public, private, and subsidized private schools in Chile. It is also important to incorporate other subjects such as language or history into these types of projects, to be able to identify in which educational sectors the use of mobile gamification technologies has a greater influence. Finally, motivational aspects need to be further developed to find those underlying elements in young people and children that allow for a better adoption of educational processes supported by technology.

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Hydrogen as an Energy Vector: Analysis of the Global Development on Decision-Making Support Systems

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Abstract. Today, the implementation of energy systems based on renewable energies is proposed as one of the different measures to address climate change. However, in this context, investments in the security and robustness of these systems are crucial. Among renewable energy sources, hydrogen production has emerged as an environmentally friendly energy solution for addressing climate change. However, regarding the systematic literature review presented in this research, there are still several research challenges in decision-making for designing a hydrogen supply chain. No study has assessed the hydrogen supply chain with all its stages from a sustainable perspective. Furthermore, despite their potential, a significant challenge is developing hydrogen in Africa and Latin America.

Keywords: Hydrogen · Supply Chain · Sustainability

1 Introduction

Climate change is one of the most critical concerns facing the world today due to its various consequences, such as glacier melting, climate disasters, resource scarcity, and drought, among others [1]. To mitigate the impacts of climate change, efforts have been made to transition towards a sustainable and environmentally friendly future, including different governmental initiatives, such as the United Nations' Sustainable Development Goals or the Paris Agreement [2]. Particularly, intervention is needed in specific productive sectors, such as energy and transportation, that generate the most significant negative environmental effects on the planet. Specifically, in the European Union, energy is responsible for 77.01% of greenhouse gas (GHG) emissions, while transportation contributes one-third [3].

Despite the energy sector contributing significantly to GHGs, there are several alternatives to support GHG emissions reduction by transitioning from a

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fossil fuel-based energy sector to one predominantly composed of unconventional renewable energies and synthetic fuels, including photovoltaic solar energy, hydroelectric power, nuclear energy, carbon utilization, and storage, bioenergy, and hydrogen [4]. However, as we move towards a renewable energy-based system, prioritizing energy security becomes crucial, and investments in robust networks are required.

Among the renewable energies, hydrogen production has emerged as an environmentally friendly energy solution to address climate change [5]. This is due to its zero carbon emissions during use (it does not contribute to global warming) and its abundance in the Earth's crust. However, hydrogen is not naturally found in its pure form on our planet, so various techniques must be applied to produce it. Hydrogen is categorized into four types (colors) based on the energy source used in its production: (1) Black, derived from coal; (2) Gray, generated from natural gas; (3) Blue, produced from natural gas with carbon dioxide capture; and (4) Green, synthesized using renewable energy sources [6]. Additionally, it can promote the hydrogen economy, bringing forth other benefits such as job creation, improving air quality in sectors reliant on fossil fuels, and reducing the country's energy dependence, among other advantages [7].

The International Renewable Energy Agency (IRENA) estimates that by 2050, hydrogen will account for approximately 12% of the world's energy consumption. It has identified Chile, Morocco, and Namibia as the countries that could emerge as exporters of green hydrogen [8]. In this context, this article presents a literature review on hydrogen decision-making support systems for designing the hydrogen supply chain worldwide. This assessment allows for identifying which decisions, methodologies, criteria, and constraints or requirements have been considered for the supply chain design, as well as the cases of application.

2 Materials and Methods

A systematic literature review was implemented in three stages. The first stage corresponds to defining a strategy search in which (1) keywords associated with the research subject, (2) the database used to obtain the research documents, (3) the search period, and (4) the search equation are defined. In the second stage, a bibliometric analysis examines the co-occurrence of keywords within the articles retrieved from the chosen search engines. As a result, the search algorithm is adjusted. In the final stage, studies are reviewed, assessing their titles, abstracts, and keywords in a first filter. The selected documents correspond to those related to the research topic: decision-making support systems for hydrogen development. Then, a full review procedure was carried out for the document assessment.

This review seeks articles on decision-making support systems, including tools, models, or platforms for designing the hydrogen supply chain worldwide. In this context, the defined keywords are hydrogen, green hydrogen, model, tool, platform, decision-making, including their variations found in the literature.

We examined databases of bibliographic references and scientific journal papers listed in Scopus and Web of Science. The publishing dates were restricted to ten years, from 2012 to 2022. As a result of both searches, 338 and 134 documents were obtained, respectively, as presented in Fig. 1. The search equation used in both databases, Scopus and Web of Science, can be found in the Appendix.

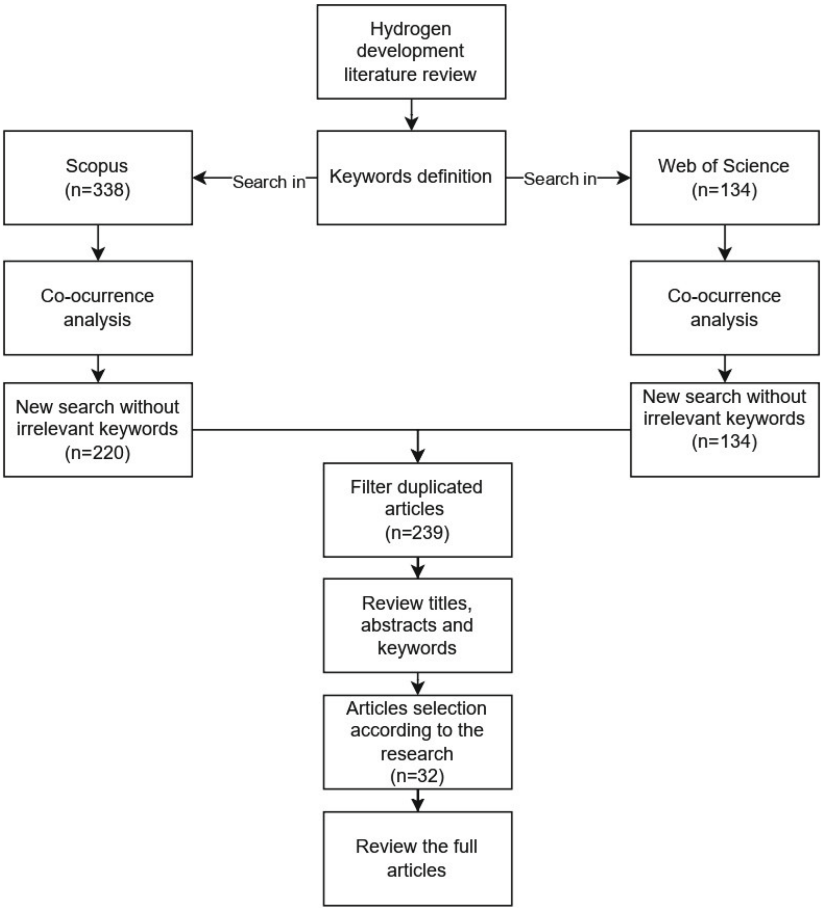


Fig. 1. Graphical methodology for literature review procedure

Then, the co-occurrence analysis was conducted without considering duplicate articles. Figure 2 illustrates the first co-occurrence analysis of the keywords from documents retrieved from Scopus and Web of Science. Using VOSviewer software, Fig. 2 reveals four prominent groups of related keywords. Notably, these groups focus on hydrogen production (blue group), decision-making (red group), articles related to terms like pH and chemistry (green group), and a group of less frequent words such as nonhuman animal and drug effect, among others (yellow

group). It's worth mentioning that this latter group is irrelevant to the search objective. Furthermore, the number of repetitions of the keywords, which determine the size of the nodes, indicates that there is greater interest in topics related to decision-making regarding hydrogen production, storage, and multi-objective optimization. Figure 2 reveals that some articles deal with themes unrelated to decision-making tools for designing hydrogen supply chain hydrogen. In this way, the keywords that are irrelevant to the search are filtered to execute a new search, as presented in Fig. 1. The keywords excluded are: human, animal experiment, hydrogen sulfide, ph, chemistry, and finally, hydrogen peroxide, resulting in a new search equation for Scopus and Web of Science, they can be found in the Appendix. Following the literature review, we used a filtering method to remove identical papers, yielding 239 for further evaluation, as detailed in Fig. 1. Then, we systematically evaluated the title and abstract of these papers. We chose those dealing with implementing models, methods, or systems to support decision-making for designing a hydrogen supply chain as an energy vector. Finally, we selected 32 articles for further analysis.

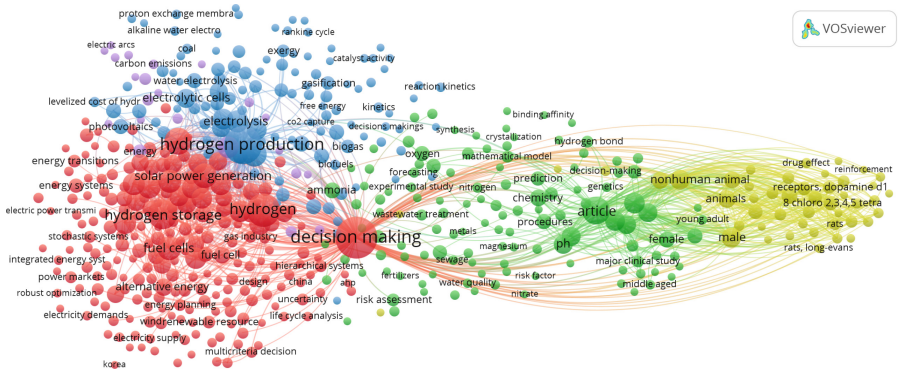


Fig. 2. Initial co-occurrence analysis for the search information from Scopus and Web of Science (Color figure online)

3 Results and Discussions

The 32 selected articles were analyzed through the co-occurrence of their keywords using VOSviewer software, as presented in Fig. 3. Figure 3 shows that the keywords of the selected articles are interconnected in decision-making using optimization regarding renewable energy sources (red groups of words) and multi-criteria related to location, site selection, production, and storage of hydrogen (green group of words).

Then, the 32 selected articles were analyzed and classified according to the sustainability dimension studied (economic, environmental, technological, social,

and political) [9], the type of article (model, framework, tool), the model description, the supply chain stages covered, and the countries where these investigations and case studies have been developed.

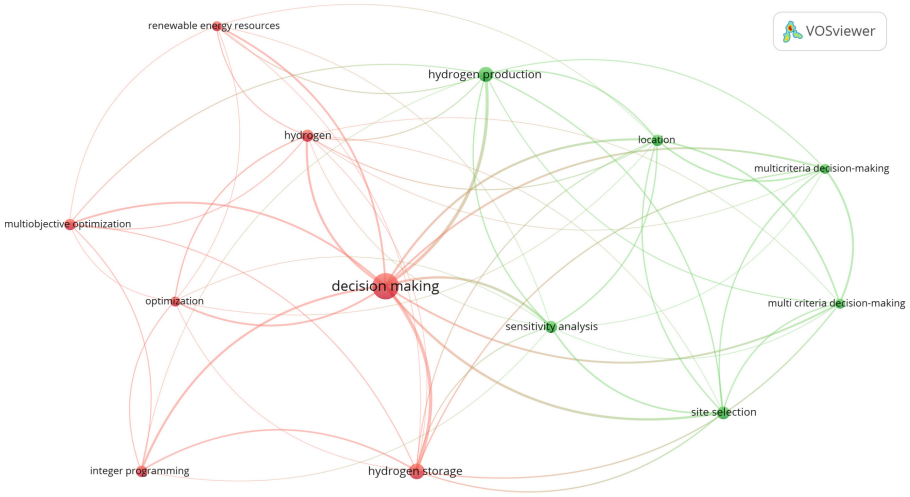


Fig. 3. Co-occurrence analysis for selected articles from Scopus and Web Of Science

The economic dimension involves economic variables that determine the performance of the organization and its economic viability. The social dimension refers to the effects of the development of green hydrogen on society, both positive and bad, including societal acceptance and governmental support. The political dimension is understood as the legal and governmental policies, such as taxes and subsidies [9], and building restrictions in specific locations, for example, in areas inhabited by native or protected areas. The environmental dimension refers to the reduction in the emission level of carbon dioxide, the environmental impact, global warming potential, and wastewater management. The technological dimension is understood as the production, transport, and storage technologies available for the green hydrogen industry [9].

Most articles, such as [22,28], examine more than one sustainability dimension. They consider all aspects of sustainability integrated into various methods or measures. For example, capital costs, the national market to be covered, and hydrogen generation expenses are all considered in [28]. On the other hand, in terms of societal elements, it applies social and political acceptance and the creation of new employment, among other things. Figure 4 depicts the sustainability combination elements, with 87.5% considering economic considerations.

Regarding the type of article, 100% of the selected articles consider mathematical models. In addition, they can be self-defined as tools or frameworks, as shown in Fig. 5a.

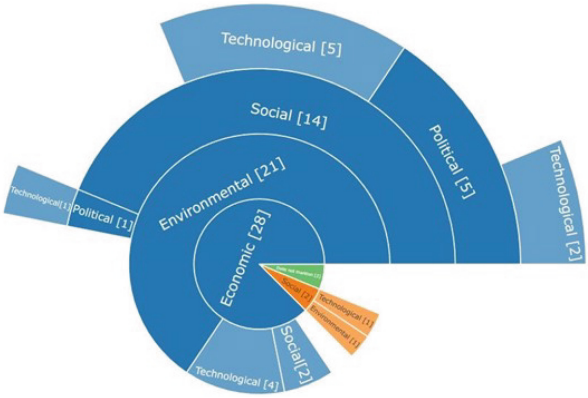


Fig. 4. Sustainability criteria evaluated

(a) Article type (b) Model type

Fig. 5. Article and model type studied in the articles. MCDM stands for multi-criteria decision-making, and Hybrid MCDM represents research that utilizes more than one MCDM method.

Alongside the development of research considering hydrogen as an energy vector and its relation to decision-making, various mathematical models exist to provide decision-makers with a comprehensive understanding of their intended implementations. For instance, by employing multi-criteria analysis methods to assess different location options for a hydrogen production project, decision-makers can ascertain the optimal choice based on their preferences. Furthermore, when designing a supply chain, multi-objective optimization models serve as an excellent alternative, aiming to achieve the best supply chain considering various alternatives such as production technologies, project location, and transportation, among others, always considering the different objectives set by the decision-maker or stakeholders. Thus, the selected articles analyze the type of model utilized in the research, with the results presented in Fig. 5b. In the analysis of Fig. 5b, 75% of the articles studied used at least one multi-criteria approach, with 50% employing the Analytic Hierarchy Process (AHP) to give weights to various criteria. [27] use a decision-making support system to

collaborate with authorities to find appropriate solar energy production locations to create hydrogen energy to power Algeria's transportation system. Multicriteria decision-making and spatial information systems are used to accomplish this. Similarly, [40] aim to find the best locations in the Iranian province of Fars for hydrogen production using wind and solar energy stations by taking into account factors such as solar energy potential, wind energy potential, population, air temperature, natural disasters, altitude, relative humidity, cost, and topography, and distance from main roads, thus covering economic, social, environmental, and political factors. The models used in this study serve various purposes, which means they have a precise aim regarding how they aid decision-making. These decisions were divided into four categories: (1) design decisions, (2) location decisions, (3) sustainable production decisions, and (4) other decisions. For example, [11] suggests evaluating eleven hydrogen transporters using a multi-criteria decision-making support tool. In particular, articles that propose decision-making models using multi-objective optimization methods are selected for further analysis. This analysis considers different aspects, such as the type of optimization applied, the proposed decisions model allows address, the variables considered, and finally, the supply chain evaluated. [33] assist the design and operational decisions of a green hydrogen production supply chain based on wind energy in this section. To minimize the total daily costs of the entire supply chain, a multi-objective optimization model is used, which includes obtaining energy sources through land-based and offshore wind, hydrogen production, transport to the storage location, distribution to the service station, and delivery to hydrogen demand. This model provides for decisions on the number, site, size, and capability of wind farms, production, storage, and transportation, as well as the method and quantity of hydrogen transported between production and storage facilities. Other articles, such as [37], use these decisions to design the supply chain for hydrogen production and later use in fuel cell electric vehicles using a single-period multi-objective optimization model with three objectives: minimizing total costs, global warming potential, and security risk. These articles support green hydrogen generation and hydrogen production that emits carbon dioxide. On the other hand, [34] develops an optimization model for the supply chain under emissions constraints. As a result, the decisions proposed in this article are production: type, number, capacity, location, and plant production rate; carbon capture and storage (CCS): type, number, and distance of hydrogen plants with CCS; and pipelines; hydrogen storage: type, number, capacity, location, and average inventory per network.

Table 1 shows the supply chains evaluated by the articles that propose optimization models (whether single-objective, multi-objective, single-period, or multi-period).

Figure 6 represents the longest supply chain examined among the analyzed items, with seven steps. It also illustrates the proportion of optimization articles that handle each supply chain step, with 100% of the articles evaluating hydrogen production from various energy sources (Table 2).

Table 1. Optimization articles assessment. SCSE = Supply Chain Stage Evaluated; OMC=Optimization model Characteristics; ES = Energy Source; P = Production; T = Transportation; S = Storage; D = Distribution; RS = Refuelling Station; FU = Final Use

Ref	SCSE							OMC		
	ES	P	T	S	D	RS	FU	Mono objective	Multi objective	Multi period
[12]	x	x		x	x				x	x
[18]	x	x		x				x		
[24]	x	x	x	x			x		x	
[29]		x						x		
[30]	x	x		x	x				x	
[33]	x	x	x	x	x	x	x	x		
[34]	x	x	x	x				x		
[35]		x		x				x	x	
[37]	x	x		x	x	x			x	x
[38]		x	x	x	x	x			x	
[39]		x							x	

The most extensive supply chain is possible because the hydrogen production is located at a certain distance from where the hydrogen will be stored, adding one more stage. Despite this, [12] models a device for storing excess wind energy by electrolyzing hydrogen. This research examines hydrogen storage in tanks and its subsequent transfer through pipelines to hydrogen consumption, primarily made of ammonia and fertilizers. It creates a multi-objective and multi-period optimization to optimize system dependability while minimizing total costs and energy losses; thus, its supply chain consists of five stages: energy sources, production, storage, transit, and consumption. However, no research has assessed the hydrogen supply chain with all its stages from a sustainable perspective.

Figure 7 depicts the distribution of research by country of application. Asia, Europe, and North Africa are predominant, while China has the highest number of articles. However, Africa and Latin America lag despite their hydrogen potential. Therefore, a significant challenge is to develop decision-making support systems adapted to these territories to support hydrogen development as an energy vector. In this regard, it is important to determine whether there is research in the countries shown in Fig. 7 with great potential for unconventional renewable energies, such as Chile.

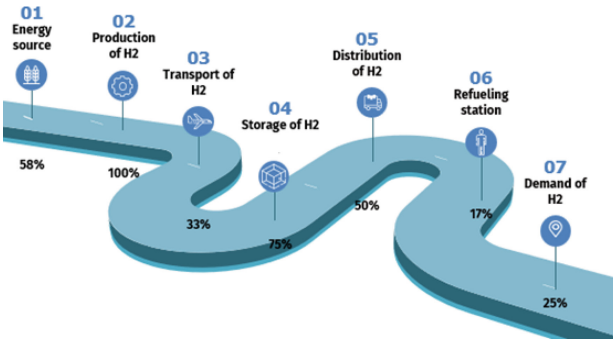
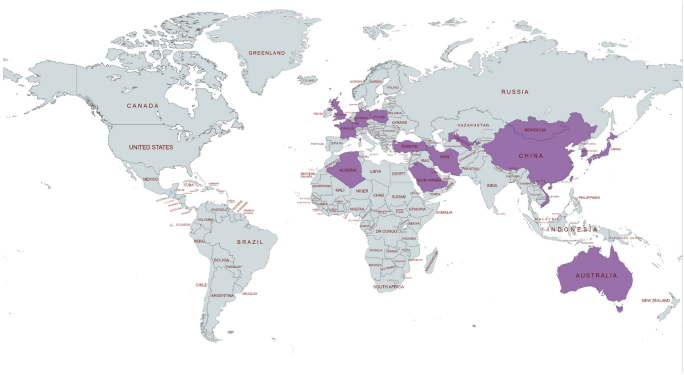


Fig. 6. Hydrogen Supply chain stages



Country	Number of Case Studies
Algeria	2
Australia	1
China	5
France	2
Germany	2
Iran	2
Japan	1
Korea	2
Mongolia	1
Poland	1
Saudi Arabia	1
Taiwan	1
Türkiye	1
United Kingdom	1
Uzbekistan	1
Vietnam	1
Total	**25**

Fig. 7. Case studies by country in articles analyzed

4 Conclusions

Using mathematical models to support decision-making for designing a hydrogen supply chain is a beneficial tool. The development of models with multiple criteria (MCDM), multi-objective optimization models, multiple periods, and even real-time optimization models are mainly observed for the inclusion of the concept of sustainability, whether as criteria, constraints, or even objective functions.

The energy source employed in the generation of electricity and subsequent production of hydrogen is a pivotal factor impacting various aspects that necessitate careful evaluation. When non-conventional renewable sources, such as wind and solar energy, are used, their stochastic behavior may result in energy fluctuations, leading to periods of energy unavailability and moments of surplus energy. Deploying batteries to store excess energy can optimize the utilization of surplus energy, enabling its use during periods of energy unavailability, which directly affects the overall production volume. Furthermore, the cost of the overall system is significantly affected by the energy sources used, which are subject

to various factors such as energy type, geographic location, and distance from production plants. In addition, some energy sources produce greenhouse gases that are subject to taxes. Hence, evaluating the costs of different energy sources is critical to designing a complete supply chain using optimization mode

Additionally, the energy source used in hydrogen production is associated with emissions, with non-conventional renewable energy sources emitting little to no carbon dioxide. In contrast, other sources, such as coal, biomass, and natural gas, emit carbon dioxide. Carbon capture methods can be employed to comply with environmental restrictions such as carbon dioxide.

Designing a hydrogen supply chain involves evaluating the location of energy production and hydrogen production. Transportation costs are absent when hydrogen production and storage occur in the same location. Also, hydrogen storage can be in different physical states, liquid or gaseous, and different storage technologies, such as super-insulated spherical tanks and pressurized cylindrical containers. This last one affects the type of transport to be used, considering the alternatives: rail tanker, truck tanker, rail tube, trailer tube, and pipelines.

Finally, Africa and Latin America lag despite their hydrogen potential. Therefore, a significant challenge is to develop decision-making support systems adapted to these territories to support hydrogen development as an energy vector.

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Appendix

Search Methodology

Search Equation

For the Scopus search, we defined the research equation as "TITLE-ABS-KEY ((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making")) AND (LIMIT-TO(PUBYEAR, 2022) OR LIMIT-TO(PUBYEAR, 2021) OR LIMIT-TO(PUBYEAR, 2020) OR LIMIT-TO(PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO(PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO(PUBYEAR, 2012)) AND (LIMIT-TO(DOCTYPE, "ar"))"

For the Scopus search, we defined the research equation as "TITLE-ABS-KEY((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making")) AND (LIMIT-TO(PUBYEAR, 2022) OR LIMIT-TO(PUBYEAR, 2021) OR LIMIT-TO(PUBYEAR, 2020) OR LIMIT-TO(PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO(PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO(PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO(PUBYEAR, 2012)) AND (LIMIT-TO(DOCTYPE, "ar"))"

While for the search in Web Of Science the following search equation was used "((TI=((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making"))) OR AB=((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making"))) OR AK=((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making"))"

New Search Equation

"TITLE-ABS-KEY ((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making")) AND NOT KEY(human) AND NOT KEY("animal experiment") AND NOT KEY("hydrogen sulfide") AND NOT KEY(ph) AND NOT KEY(chemistry) AND NOT KEY("hydrogen peroxide") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO(PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012))". And the new search equation for Web of Science is: "((((((TI=((hydrogen OR"green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making"))) OR AB=((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making"))) OR AK=((hydrogen OR "green hydrogen") AND (model* OR tool* OR platform*) AND ("decision making" OR "decision-making")))) NOT AK=((Human OR "animal experiment" OR "hydrogen sulfide" OR ph OR chemistry OR "hydrogen peroxide"))". With this new search, 220 and 130 articles were obtained, respectively.

Table 2. Summary of the analyzed articles. Ref=Reference; Ec= Economical; En= Environmental; Te= Technological; So= Social; Po= Political; CSC= Case Study Country.

Ref	Purpose	Criteria					CSC
		Ec	En	Te	So	Po	
[10]	Evaluate twenty-three options for flexibility in terms of energy management.	x		x			GR (x)
[11]	Develop an MCDM model to evaluate multiple hydrogen carriers.	x	x				AU and JN

continued

Table 2. continued

Ref	Purpose	Criteria					CSC
		Ec	En	Te	So	Po	
[12]	Develop a decision-making tool to minimize cost and energy losses, and maximize the reliability of a small-scale wind to hydrogen system.	x		x			DZ
[13]	Determine the appropriate location for solar hydrogen production plants in 13 provinces of Uzbekistan.	x					UZ
[14]	Determine suitable areas for building wind farms to produce hydrogen.	x			x		IR
[15]	Identify the best location for hydrogen generation from wind energy using multiple criteria decision-making (MCDM) techniques.			x	x		SA
[16]	Develop a scientific method for the location of photovoltaic coupled hydrogen storage projects.	x	x		x		MN
[17]	Provide a model for the site selection of the photovoltaic hydrogen production project.	x	x	x	x		CN
[18]	Optimize the configuration of the integrated natural gas-wind-photovoltaic-hydrogen energy system and analyze the optimization results to serve decision-making.	x	x				CN
[19]	Build a two-stage location optimization model based on big data of geographic information to provide a special guide for the HRS site decision.	x			x		CN
[20]	Optimal site selection for hydrogen storage with wind energy using GIS and MCDM approach.	x	x	x			CN
[21]	Develop a systematic prioritization framework for hydrogen production pathways from a sustainability perspective	x	x	x			CN (x)
[22]	Identify optimal energy alternatives for investment in hydrogen production.	x	x	x	x	x	CN (x)
[23]	Evaluate the sustainability of different options for green hydrogen production.	x	x	x	x		EG and AU (x)
[24]	Develop a methodological framework for quantifying the potential social benefits of hydrogen fuel cell vehicles.	x	x		x	x	FR
[25]	Design an approach to decide the site of the hydrogen energy plant.	x	x	x	x		IN (x)
[26]	Site selection of hydrogen production facilities from hydrogen sulfide decomposition.	x	x	x	x		TR
[27]	Identify priority sites for solar resources to produce hydrogen energy for the transport sector.	x		x			DZ

continued

Table 2. continued

Ref	Purpose	Criteria					CSC
		Ec	En	Te	So	Po	
[28]	Developing a dynamic and flexible technology roadmap using a combination of the classical roadmap development method with a novel multi-criteria decision-making approach and fuzzy multiple aspects.	x	x	x	x	x	Does not mention
[29]	Implement a real-time large-scale optimization decision support tool for hydrogen under uncertainty.			x			ES (x)
[30]	Identify the best hydrogen infrastructure routes taking into account local factors such as the location of hydrogen supply and demand, and the distribution between the location of hydrogen production and hydrogen demand points.	x	x				DE
[31]	Selection of the site of the hydrogen power plant in Vietnam under fuzzy environment conditions.	x	x	x	x		VN
[32]	Identify the most suitable geologic structure for underground hydrogen storage.		x				PL
[33])	Develop an strategic planning of a renewable hydrogen supply system using land-based and marine wind energy.	x		x			KR
[34]	Optimize the hydrogen supply chain under emission constraints.	x	x	x		x	DE
[35]	Design a five-step HSC (energy source, production, transportation, storage and refueling station) using multi-objective optimization, minimizing cost, environmental impact, and security risk for a multi-period problem.	x	x				FR
[36]	Evaluate hydrogen production technologies in China, based on the intuitional theory of fuzzy sets with interval values.	x	x		x	x	CN
[37]	Design a three-level HSC (production, storage, and transportation) taking into account the minimum cost, minimum environmental impact, and minimum security risk.	x	x				UK
[38]	Design hydrogen infrastructure with a profitable H_2 supply, safety, and CO_2 mitigation.	x	x				KR
[39]	Find a set of optimal solutions by performing a multi-objective optimization that simultaneously satisfies the maximization of the thermal efficiency of the SMR process and the minimization of CO_2 emissions from the process.		x		x		KR (x)
[40]	Determine the best locations in the Fars province for hydrogen production from energy produced by wind and solar hybrid stations.	x	x		x	x	IR
[41]	Develop an evaluation model to assess hydrogen fuel cell applications and thus provide a decision-making tool for decision-makers.	x	x		x		TW

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SafePlace: A Mobile Application Prototype for Supporting People with Anxiety

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Abstract. Anxiety is a mental disorder present worldwide, with a notable increase in recent years. In response to this challenge, technological advancements offer opportunities to address social problems, and this study focuses on the development, evaluation, and testing of a mobile application specifically designed to improve anxiety. This work proposes an application that offers interactive resources and connection with mental health professionals for personalized intervention. The application is designed for Android systems and utilizes Microsoft cloud database services to ensure data accessibility, as well as components that facilitate the final development of the application. Its interface was built considering various factors related to manipulation by different types of users, and it has been optimized to be simple and intuitive, as confirmed by usability survey results. The main objective is to guide users to manage their anxiety more effectively, providing relevant tools and resources for their self-control and emotional well-being. Ultimately, the results show that anxiety is reduced with the progressive use of the developed application.

Keywords: Anxiety · Mental Disorder · Mobile Application

1 Introduction

Anxiety is a prevalent disorder globally, affecting people of all ages. According to the World Health Organization (WHO) [22], in 2019, 301 million individuals suffered from this disorder, making it the most common mental health issue. In Ecuador, data reveals a significant increase in consultations for mental disorders. Between January and July 2023, 619,781 consultations were recorded, reflecting a 58% increase compared to the previous year [27]. This growth underscores the urgency of addressing mental health in innovative ways. In response to this need, this work introduces "SafePlace," a mobile application designed to support individuals with anxiety. Through an interactive interface, the application offers educational and practical resources, as well as facilitating access to mental health professionals. This approach aims to empower users, enabling them to manage

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their condition more effectively and autonomously. The "SafePlace" proposal represents a promising technological solution to the growing challenge of mental health.

This article is structured in the following sections to provide a coherent and organized presentation of the research. Section 2 focuses on related work, offering a detailed analysis that will significantly contribute to the development of the research. Section 3 covers the methodology and architecture of the developed application. Section 4 describes the results after evaluating the application. Finally, Sect. 6 presents the conclusions of the research and future work.

2 Related Work

This research highlights the importance of understanding anxiety and its origins due to its growing impact on public health. According to Macías et al. [8], there are 11 anxiety disorders classified in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V), all characterized by distress and fear, which require specialized attention. Chacón et al. [9] emphasize that anxiety, commonly associated with suffering and disability, imposes significant social and economic burdens. Agudelo et al. [35] indicate that anxiety and depression are widely reported disorders in health centers, affecting the general population. Additionally, Pacheco et al. [25] discuss separation anxiety in children as a normal and anticipated part of child development. In summary, anxiety is a complex phenomenon with multiple manifestations, whose understanding is essential for its proper management and for comprehending its impact on mental health.

- **Common Types of Anxiety Disorders:** Anxiety manifests in response to challenging situations and can range from everyday worries to clinical disorders. According to Barnhill [3], anxiety is a natural reaction to threats or psychological stress, related to fear and essential for survival, triggering fight or flight responses in dangerous situations. It is crucial to understand the unique characteristics of each type of anxiety to develop an approach that improves the management and treatment of these disorders. According to NIH Medline Plus [9], there are four predominant types of anxiety: Generalized Anxiety Disorder, Panic Disorder, Phobia-Related Disorders, and Social Anxiety Disorder. These different types of anxiety disorders share the fundamental characteristic of generating intense and disproportionate responses of fear or worry in specific situations.
- **Psychological Treatments for Anxiety Disorders:** Pérez et al. [29] state that "There are two types of treatments recommended by the National Institute for Health and Clinical Excellence for anxiety disorders: medication and psychotherapy." When referring to the psychotherapeutic treatment of a disorder, two fundamental aspects must be taken into account. First, the criteria that lead to considering a treatment effective or appropriate. Second, the etiology of the disorder, that is, the causes understood to be determinant in its development and persistence. This is crucial because these causes guide the design and implementation of various treatment programs [29].

- **Generalized Anxiety Disorder (GAD):** Focusing on Generalized Anxiety as an independent disorder, it can be stated that its development involves the convergence of various elements and variables. Notably, genetic, biological, environmental, and psychological factors can play a role in its origin [20].
- **Social Anxiety Disorder (Social Phobia):** One of the most observable disorders in people with phobias is the fear or insecurity of their environment. The DSM-5 diagnostic criteria consultation guide states that this disorder generates "Intense fear or anxiety in one or more social situations in which the individual is exposed to possible scrutiny by others. Examples include social interactions" [2]. For example: having a conversation, meeting unfamiliar people, and performing in front of others.

2.1 Benefits of Entertainment-Focused Applications for Improving Mental Health

Recent research in the field of mental health is embracing innovative technologies to enhance the diagnosis and treatment of psychological disorders. Di Matteo et al. [10] explored the use of microphones in smart devices to assess symptoms of anxiety and depression, while Kathrin et al. [15] investigated the application of artificial intelligence in mental health tools, demonstrating how AI can optimize patient treatment. These studies illustrate the potential of emerging technology in identifying emotional states through voice. The analysis also integrates the findings of Green et al. [11] and Lucy et al. [32], who utilized technology to improve psychological well-being, inspiring the development of a mobile application that specifically addresses mental health needs. Additionally, O'Dea et al. [24] and Tsirmpas [34] provided evidence of the positive impact of apps on the support and well-being of users with disorders such as anxiety and Attention-Deficit/Hyperactivity Disorder (ADHD), highlighting the effectiveness of cognitive-behavioral therapy and technological support in these contexts.

This body of research underscores the growing importance and efficacy of technological solutions in the field of mental health, indicating a promising path towards more personalized and effective treatments.

2.2 Digital Transformation in Mental Health: Integration of Human Interventions and Big Data Analysis

According to Bucci et al. [7], the digital revolution is evolving at an unstoppable pace. Big data, computing power, mobile technology, and networked information enable the transformation of service provision by adopting a digital stance in the healthcare sector, implementing new approaches, and providing tools that allow individuals to self-monitor and self-manage in ways that have been limited until now.

On the other hand, Shang et al. [31] highlight the role of human support in the effectiveness of human interventions, integrated into applications that include counseling services, education, mental health, and self-assessment of

mental health status. These metrics are scalable and validated. These applications emerge with the aim of providing a synthetic platform that supports the management and control of mental health. Similarly, according to Kornfield et al. [16], human interventions are proposed in a population of young adults, where interactive text messaging dialogues are used to obtain feedback for more precise intervention guidance.

Another idea is presented in the article by Nie and Mo [21], which focuses on using big data in higher education to analyze and identify potential cases of psychological pathologies and mental health problems in students by extracting behavioral characteristics from large datasets collected from various sources. On the other hand, Wang [37] focuses on the impact of big data mining systems on mental health analysis, exploring this effect with a particular focus on obsessive-compulsive disorder, highlighting the importance of anxiety and interpersonal relationships. For the present work, the related works of Shang et al. [31] and Kornfield et al. [16] will be taken into account, as their approach is a starting point for the proposed work. Their methods, results, and conclusions will be considered.

2.3 Advances in Cognitive-Behavioral Therapy: Positive Impact on Quality of Life and Innovative Effectiveness in Technological Intervention for Children

The study by Maj et al. [17], it's mentioned that Internet-based Cognitive Behavioral Therapy (iCBT) has demonstrated a positive impact on the quality of life of patients with anxiety and depression disorders, according to a meta-analysis of randomized controlled trials. Despite its effectiveness, moderate heterogeneity was observed among studies, highlighting the need to consider various factors that could influence the results. Recommendations for future research include addressing limitations such as a focus on short-term effects, cultural limitations, and the use of self-report measures to assess quality of life, emphasizing the importance of more comprehensive and long-term investigations.

In a different context, a study conducted by McCashin et al. [18] evaluated the effectiveness of a cognitive-behavioral therapy game in children with low mood and anxiety levels, finding a significant reduction in these symptoms. Although no significant differences were found in primary or secondary measures, both children and parents expressed high levels of acceptance and satisfaction with the intervention. These results suggest the relevance of considering certain aspects applied by this study for the analysis of similar interventions.

2.4 Exploring the Relationship: Impact of Technology on Mental Health Across Different Contexts and Populations

The article by Bhatia et al. [5], the "Manage My Pain" application is highlighted, showing that the participation of patients with chronic pain in urban and rural settings in Ontario, Canada, is associated with improvements in self-reported anxiety and pain catastrophizing. On the other hand, McCashin et al. [18] focus

on the development of an application based on the Unified Protocol to treat emotional disorders, emphasizing the need to involve both users and professionals in the design phase to ensure the effective implementation of evidence-based treatments. This finding aligns with Bhatia et al. [5] emphasis on the importance of understanding the factors affecting ongoing engagement and clinical outcomes in patients with chronic pain.

Together, these articles highlight the importance of understanding how different technologies, whether specific applications or internet therapy, impact user engagement and clinical efficacy in diverse contexts such as chronic pain and post-treatment psychological distress in childhood cancer. This comparison underscores the ongoing need for research to explore not only the effectiveness of these technologies but also their effective implementation and adaptability to diverse populations and clinical contexts.

2.5 Implementation Perspectives: Mobile Applications and Mental Health

According to Bendtsen [4], a positive psychology intervention is implemented through a mobile application targeting university students in Sweden. Research shows that the intervention is effective in increasing positive mental health and reducing symptoms of depression and anxiety. However, according to Renfrew [30], a comparative study with three modes of human support in a web-based mental health promotion intervention and mobile applications is conducted. Although significant improvements in mental well-being are observed in all groups, low participation in videoconference sessions affects comparisons between them.

Lastly, Prochaska [28] describes the BeMe platform, a smartphone application designed to support the mental health of adolescents in the United States. The intervention includes elements of cognitive-behavioral therapies, interactivities, live coaching, and crisis support tools. The active participation of adolescents and high satisfaction ratings for content, activities, and coaching are highlighted.

3 Application Proposal

In this section, the architecture used and the development process of the SafePlace mobile application prototype are detailed. Its aim is to provide support to individuals diagnosed with anxiety through an intuitive interface that allows the user to record their mood.

3.1 Architecture and Methodology

The SafePlace prototype was developed for mobile devices with the Android operating system (OS). For the creation of the application, client-side (Frontend) technologies such as Ionic and Angular were employed. On the other hand, on the server-side (Backend), Dotnet Core was used. Additionally, the Microsoft

Azure cloud service was implemented for deploying the Application Programming Interface (API), and SQL Server was employed as the database manager to store user information (Fig. 1).

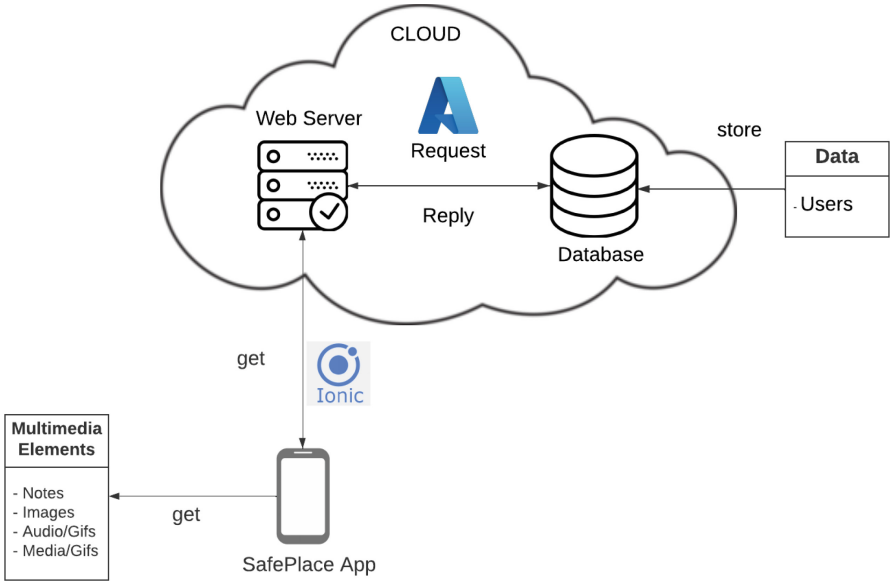

Fig. 1. Application Architecture

3.2 Development

The SafePlace prototype is specifically designed for users with anxiety. The main user actions include: 1) Registering, 2) Logging In, 3) Recording a mood state, 4) Creating personal notes, 5) Selecting multimedia content, 6) Creating a list of activities, 7) Completing an anxiety questionnaire, and 8) Using personalized attention. To carry out the aforementioned tasks, the user must be properly registered and logged in.

The data generated in step one should be stored within the SQL Server database deployed in the Microsoft Azure cloud service. This information will be used by the mobile prototype to manage requests and validate step number two, allowing user login.

To assess the severity of generalized anxiety among users of the mobile application, the Generalized Anxiety Disorder Scale (GAD-7) [33] has been used. This tool consists of seven questions designed to measure the frequency of anxiety symptoms experienced by the user(see Table 1). The total score obtained on the GAD-7 provides an objective measure of the severity of anxiety, allowing for an accurate assessment of emotional status. The inclusion of this scale

in the application provides the opportunity to effectively monitor the evolution of anxiety levels over time, as well as to identify those who may benefit from additional interventions or referrals to mental health professionals.

Table 1. Interpretation of the score on the GAD-7

Score	Interpretation
0–4	No apparent anxiety
5–9	Mild anxiety symptoms observed
10–14	Moderate anxiety symptoms observed
15–21	Severe anxiety symptoms observed

The choice of mood was based on the model of positive and negative affectivity [26], which contemplates 16 different types of moods. These are classified into four quadrants, considering the degree of affect in negative and positive levels. After registering the mood, the plan is to display relevant information about the quadrant to which the selected mood belongs.

Regarding the creation of personal notes, the user has the ability to record any information in text format that they consider necessary, timely, or simply wish to remember. The following actions have been implemented for the user: 1) create a new note, 2) edit existing notes, 3) view all notes, and finally, 4) delete any notes they deem necessary. The application has a personalized attention section that leverages the question and answer platform of Just-Answer [1]. This platform features verified experts in various areas, such as medicine, allowing us to offer users the opportunity to directly contact a psychologist.

3.3 Interface

In the design of the prototype interface, a user-centered approach has been adopted, with a design that is easy to understand, allowing users to perform actions in a simple and intuitive manner. The implementation of the interface is based on the use of user interface components (UI components) belonging to the Ionic and Angular framework.

The color selection was carried out considering the principles established in color psychology [19], with the aim of creating a professional and pleasant environment for all types of users. The construction of the prototype was supported using the documentation of W3C [36].

4 Evaluation

The evaluation focuses on analyzing the impact of the SafePlace mobile application on reducing anxiety levels in university students. Surveys such as the Generalized Anxiety Disorder Scale (GAD-7) are used to measure anxiety levels

before and after interacting with the application. Additionally, usability questionnaires are employed to assess user experience and the perception of mental health professionals regarding the utility of the application.

4.1 Evaluation Proposal

The evaluations aim to determine the effectiveness of SafePlace as a tool for managing anxiety in students. To achieve this, surveys were used to assess two main aspects. Firstly, the user's initial anxiety level was evaluated using a specific survey called the Generalized Anxiety Disorder Scale (GAD-7) [33]. Secondly, the usability of the interfaces of the different sections of the application was assessed using the System Usability Scale (SUS) method [6] for students. However, for the evaluation by the professional, the User Satisfaction Evaluation (USE) survey [12] was used. These surveys provided the necessary information about usability and user perception.

4.2 Demography

SafePlace was designed to provide support to students from the Department of Computer Science at the Universidad de las Fuerzas Armadas ESPE who are facing diagnosed anxiety. With an inclusive approach, the application welcomes individuals of all genders and socioeconomic levels. Regardless of occupation, since its target audience is students, the application seeks to provide specific tools and resources to improve emotional well-being and effectively manage anxiety in this academic environment.

4.3 Scenarios

To determine the sample size, the method of calculating the sample from a finite universe was employed, applying the formula from [13]. This calculation resulted in a value of 40.18 as the finite sample size. A survey was conducted using forms on the Google platform, using the GAD-7 questionnaire. The survey results yielded scores ranging from zero to twenty-one. Based on the interpretation of the GAD-7 scores, students who scored between fifteen and twenty-one were selected, considering this range indicative of severe anxiety symptoms.

In the first scenario, considering the previous results, eighteen students were selected to whom the application prototype was provided. With the purpose of effective monitoring, it was decided to apply the GAD-7 scale at regular intervals, allowing observation of any significant changes in anxiety levels as the students interacted with the application.

Additionally, the System Usability Scale (SUS) method was implemented to evaluate the overall experience of the students. This approach provided quantitative data on the functionality and use of the application, identifying specific areas that required attention or improvements.

In the second scenario, an additional layer of evaluation was incorporated by involving mental health professionals in reviewing the application using the

USE usability method. This approach aimed to obtain a more specialized perspective on the effectiveness and usability of the application. The USE method was applied to mental health professionals, who evaluated the application in terms of its adaptation to best practices and standards in the field of mental health. This evaluation by mental health professionals complemented the feedback provided by the students, thus providing a comprehensive and balanced assessment of the application.

4.4 Results

For the evaluation stage, users selected and registered in the database will be considered. It is important to highlight that the first 5 users in the database were assigned to group members and professional staff, meaning that for this evaluation phase, students will be identified by their unique user id, starting from number 6 onwards. This is because user identifiers in the database are incremental and are ordered from 6 to 23.

In the first scenario, the GAD-7 survey was applied and focused on the population described in the demographics. This survey allowed categorizing students according to the scale presented in Table 2. Students who showed a high level of anxiety in this survey were selected to participate in the application evaluation for a period of 5 d. During this time, students carried out various tasks available in the application, primarily completing the questionnaire. This allowed observing the evolution of students' anxiety levels before, during, and after using the application.

Table 2 shows the values obtained after the evaluation period by the students. Blank spaces indicate that students did not complete the questionnaire on the mentioned days. The evolution is represented from a column showing the initial anxiety levels of each user, followed by the values recorded during the five days of evaluation, and concludes with the average of the results of the specific evaluation period for each user.

In Fig. 2, it is evident that 10 students show a slight decrease in their anxiety levels after using the application, while 8 students show an increase in their anxiety levels after using it.

The next step in evaluating the first scenario involves assessing the application using the System Usability Scale(SUS). This survey was also developed in Google Forms and delivered after the evaluation period to each student who participated in testing the application. Using the Likert scale [14], the following results were obtained, as shown in Table 3.

The results obtained in the survey range from 52.5 as the lowest score to 70 as the highest, with an overall average of 57.64 at the end of the evaluation conducted by the 18 users. Taking into account this value (57.64) and the SUS scale, it is evident that the usability of the SafePlace application falls within the range termed as marginal, indicating that the application is considered functional by the students.

In the second scenario, the USE survey was administered to healthcare professionals, specifically three psychologists. This survey, developed in Google Forms,

Table 2. GAD-7 student results.

Start date	User	Day 1	Day 2	Day 3	Day 4	Day 5	End
17	6	10	15	-	13	19	14.25
15	7	14	12	15	15	17	14.60
15	8	14	16	16	18	17	16.20
16	9	16	17	19	12	18	16.40
16	10	16	13	11	16	-	14.00
15	11	18	18	10	14	18	15.60
16	12	19	14	16	13	-	15.50
15	13	16	13	-	16	20	16.25
15	14	15	12	20	11	10	13.60
16	15	19	20	12	-	16	16.75
15	16	18	-	-	-	16	17.00
15	17	10	16	14	-	-	13.33
15	18	20	14	17	12	12	15.00
15	19	17	15	12	18	14	15.20
15	20	12	15	13	14	14	13.60
16	21	11	19	-	17	13	15.00
15	22	16	10	15	11	-	13.00
15	23	10	14	-	17	16	14.25

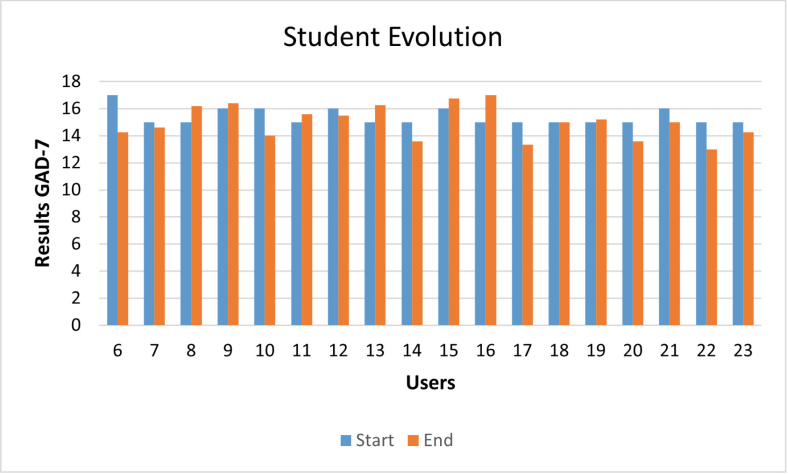

Fig. 2. Results of the students' evaluation when completing the GAD-7 questionnaire.

Table 3. Results of the students' evaluation.

User	Final Results
6	55.00
7	62.50
8	57.50
9	55.00
10	62.50
11	67.50
12	52.50
13	70.00
14	45.00
15	67.50
16	52.50
17	70.00
18	57.50
19	50.00
20	50.00
21	52.50
22	50.00
23	60.00

focused on assessing the usefulness, ease of use, ease of learning, and satisfaction with the application. The professional staff received the application for a period of five days, after which the different sections mentioned above were evaluated, resulting in the following interpretations of results for each section.

- **Usefulness:** This section consists of eight questions, and for the results, a specific average was calculated per question. Subsequently, a general average for the section was obtained, which was 5.54 out of 7. It is important to note that USE uses the Likert scale, where values from one to seven are established, with one being the lowest or poor level and seven being the highest or excellent level. Therefore, this result indicates that the utility of the SafePlace application is at a good level.
- **Ease of Use:** This section consists of eleven questions. Subsequently, a general average for the section was obtained, which was 6.39 out of 7. As mentioned earlier, it was rated using the Likert scale. This result indicates that the ease of use of the SafePlace application is at a very good level.
- **Easy to learn:** This section consists of four questions. A perfect average for the section was obtained, which was 7 out of 7(100%). As mentioned earlier, it was rated using the Likert scale. This result indicates that the ease of learning of the SafePlace application is at an excellent level.

– **Satisfaction** This section consists of seven questions. An average of 6.43 out of 7 was obtained for this section. As mentioned earlier, it was rated using the Likert scale [23]. This result indicates that satisfaction with the SafePlace application is at a very good level.

5 Discussion

Upon concluding the evaluation of the application, scores on the USE and SUS questionnaires were observed, which, although showing slightly positive data, also highlighted areas clearly in need of improvement. Users found the application easy to use, but also emphasized the need to enhance certain aspects of the interface, such as data presentation, limited multimedia content, and the waiting time for registration and login. This discussion regarding the deficiencies underscores the importance of addressing usability and privacy concerns, ensuring that SafePlace is not only effective in reducing anxiety but also reliable and secure for its users. These aspects were corroborated following recommendations from professionals during the evaluation process, suggesting that SafePlace may have a positive impact on the emotional well-being of students with anxiety.

This study focused on seeking a specific solution for anxiety control, considering a change of 2.73% and a key factor: the duration of app usage before the tests, which was 5 d. The general anxiety levels of users were tracked in various situations, regardless of their gender, age, or other factors that could influence. In conclusion, it is highlighted that SafePlace represents a valid starting point for research, but requires further improvements and evaluations, especially considering a broader population.

6 Conclusions and Future Work

In this research work, a prototype mobile application was designed, developed, and evaluated targeting individuals with anxiety issues. The users for this study were university students. These users had access to the functional prototype of the application, which allowed features such as creating notes, recording moods, and interacting with multimedia content. Additionally, a personalized care module was implemented using a platform where professional help could be obtained. Primarily, students could respond to a questionnaire implemented within the application, which allowed tracking the anxiety levels of each student over time during the testing period, which lasted for five days.

The initial results of the anxiety level of the 18 students revealed an average of 15.39, while the final average was 14.97 after the mentioned period. This slight decrease of 0.42 units represents a 2.73% change. It is worth noting that this amount indicates a reduction in the level of anxiety, suggesting that the application had a positive impact on the students.

SafePlace, reflects a fundamental commitment to the mental well-being of students. With the intention of addressing a prevalent issue in society, a prototype mobile application has been conceived and evaluated to assist individuals

with anxiety. With the analyzed results, a positive trend in anxiety reduction among users during the trial period was evident. However, areas for improvement have been identified, particularly in user experience and data security. In conclusion, SafePlace not only represents an advancement in using technology for mental health but also a continued commitment to innovation and improvement to provide effective and meaningful support to users in their pursuit of emotional well-being.

SafePlace is initially developed for the Android operating system; however, there are plans to implement its functionality on the iOS operating system. Considering the feedback from students and professionals, there are plans to release a version that allows for payment for the service provided. Additionally, integration with smartwatches will be explored to expand the collection of relevant data for anxiety verification, such as heart rate and other physiological parameters. Furthermore, efforts will be made to enhance user data security through password encryption and encryption of user-entered data in the application.

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Cost-Effective Tension Testing System for Plastics Industries

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Abstract. To determine mechanical properties or other relevant parameters of plastic materials, devices such as tensile testing machines are widely used. However, these procedures are performed with relatively expensive equipment that is not easily available in educational institutions or companies. For this reason, the following work presents the development and validation of a cost-effective machine capable of performing tensile tests with uniaxial loads on plastic materials. The main characteristics regarding the mechanical, electronic, and software design that have been developed and implemented for the correct operation of the machine are briefly and clearly disclosed. Likewise, the calibration process was performed using a known spring elastic constant. Additionally, the application and validation of the machine were carried out by comparing tensile tests done on the plastic straps with tests done in another machine. The results obtained by the developed machine are similar to those estimated by the validation machine in terms of mass and strain, obtaining an average accuracy of 2.46% and 2.17%, respectively. Finally, the machine sale price was estimated at $1,908 USD, a reduction cost of 68.2% compared with other similar machines in the industry.

Keywords: Tensile test · cost-effective machine · plastic materials · mechatronics design

1 Introduction

Currently, evaluating the mechanical properties of plastic materials is of utmost importance in a wide range of industries, from consumer products to engineering materials. Since the 70 s, using said materials has increased considerably by approximately ten times [1]. This exponential growth underscores the anticipated expansion and significant advancements within the fields of materials and polymer science in the forthcoming years [2–4], so it becomes pertinent to emphasize the analysis of the mechanical properties of certain materials, specifically plastics.

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The properties of interest for a given material depend on the application for which the material will be used. Properties like Young's modulus, toughness, elongation until break, tensile strength, and viscoelasticity [5] must be taken into account and are considered the most used for several processes [4]. Various methods are employed to obtain the mechanical properties of plastics. These methods include tension testing for elastomers and fibers, creep testing, dynamic mechanical analyses for viscoelastic plastics, short-term and long-term tensile testing, impact toughness, hardness testing, and fatigue testing [6,7].

One of the most influential and complete methods to obtain these properties is the tensile test [8,9], in which the stress-strain graph of the material can be obtained. The resulting plot represents the material's response under uniaxial tension, crucial for designing structures and understanding material behaviour [8,10]. This test in plastics provides information about the material's wide range of stress-strain characteristics, from brittle to hard to ductile [5]. Thus, information allows for different types of plastic alloys to be created to improve their characteristics [11–14].

Therefore, a tensile testing machine or a universal testing machine (UTM) has great importance in material developments, where the device produces a load-extension curve as its output, which is then typically converted into a stress-strain curve—where stress is based on the initial cross-sectional area—or a stress percentage elongation curve [15,16].

1.1 Related Works

Several research studies have addressed the design and development of tensile testing machines for different applications. For example, the study of [17] discussed the development of a low-cost machine for educational use, which included both the mechanical and electronic structure, along with calibration using pressure and diameter to calculate stress and area. The work of [18] focused on understanding the tensile properties of materials such as polypropylene, using a sensing block system and a complex data acquisition system to analyze the results. Additionally, the work of [19] presented a study about the portability of testing machines, highlighting their use in different environments and their integration of electromechanical units with electronic control for precise data processing. Finally, the study in [20] describes the design of a desktop tensile testing machine, emphasizing the generation of contour maps and strain/elongation measurements, using LabView for control and data processing.

Another set of researchers has focused on the manufacturing and calibrating tensile testing machines in both mechanical and electronic aspects. For example, the work in [21] detailed a UTM machine's manufacturing and assembly procedures, emphasizing electronic precision and mechanical rigidity. Similarly, in [22], another design of an automated UTM was presented, focusing this time on integrating mechanical and electronic components for precise movement control and data acquisition. Additionally, the study of [23] described the development of a portable UTM for medium-strength materials, highlighting both its electronic

and mechanical components and the calibration process to ensure accurate measurements.

In contrast, the work in [24] presented a composite material testing machine design methodology, emphasizing the choice of electronic components and the calibration process. Similarly, another study presented in [25] described the design of a testing machine to determine the tensile strength of high-density plastic sheets, highlighting both the mechanical and electronic aspects of the design. Lastly, the work of [26] reviewed the literature on uniaxial tensile testing of rubber-type materials, focusing on the construction and computational control of testing machines.

Also, some researchers have focused on designing and controlling high-speed tensile testing systems. For example, in [27], a new tension mechanism design for high-speed testing machines is presented, using motorized linear systems and computer-aided engineering techniques. Additionally, the study of [28] described a field programmable gate array (FPGA) based measurement and control system for a high-speed dynamic tensile testing machine, obtaining precise linear motor control and real-time data acquisition.

Finally, it is essential to highlight the study of [29], which described the design of a biaxial testing machine to measure the mechanical properties of polymers at quasi-static strain rates. It used stepper motors, micro-stepping controllers to control movement, and an Arduino microcontroller for electronic control. In addition, the calibration process involved using a UTM to adjust the load cells.

1.2 Main Contributions

The previous section shows that testing machines are widely used in material research and product development. However, certain aspects of the machine have not yet been studied. For this reason, this work aims to cover these gaps with the following contributions:

- The machine was constructed with uniaxial loads directed towards plastic materials, considering the mechanical system that increases the torque of the displacement system of the clamps with a single stepper motor with gears and chains.
- The prototype presents an economical and effective data acquisition system showing real-time stress-strain graphs.
- The tensile test conditions can be modified depending on the sample and material type, creating an adaptive testing machine.
- The paper elucidates a novel calibration method utilizing a spring with well-defined characteristics, ensuring accuracy and reliability in the measurement of tensile properties.
- Finally, to validate the system's performance and show the possible application of the system, the machine was used to verify the strength and strain of an industrial plastic strap.

This work is structured as follows: Sect. 2 presents the methodology that was followed to create the machine, where the components used for both the electronic and software part and the mechanical part are detailed, together with information about the functionality of the machine, and how it has been calibrated and validated. Section 3 details the machine finishes and the results obtained in the experimental part concerning calibrating and testing outcomes with their respective discussion. Section 4 shows the cost analysis of the machine and compares it with similar machines in the market. Eventually, in Sect. 5, the conclusions obtained are made known.

2 Methodology

2.1 Mechatronics Design

Mechatronics design integrates mechanical, electronic, and systems engineering for complex devices [30], often substituting mechanical functions with electrical ones for improved efficiency [31]. Once that is understood, the mechatronics design of the machine described in this document is presented below, where emphasis is placed on the main components corresponding to the three essential aspects mentioned above for this type of designs.

Mechanical Design: In this segment, the mechanism used to provide uniaxial movement in the machine is described. First, a double-column structure was made, where two steel shafts and an endless screw with a pitch of 2.5 mm were located in each of the sections that have been established as structures to a couple of said components (see Fig. 1). This geometry made it possible to locate the machine clamps in the middle of the structure. The upper clamp was fixed to the machine, while the lower clamp is the one that moves from top to bottom thanks to the endless screw, taking into account that necessary bearings were used to obtain fluid movement concerning the screw.

For the movement of the endless screws, a chain-sprocket mechanism was used, where the smallest sprocket was coupled to a Nema 34HS31 motor with a torque of 4.5 Nm (see Fig. 1). Then, using a chain of transmission, it was possible to move the larger gears that were attached to the bottom of each of the screws that were mentioned in the previous section. In addition, the transmission ratio is 2.85:1, which has achieved a lower speed in uniaxial movement. However, the torque increased, thus causing a greater axial force to move the lower clamp.

Electronic Design: Concerning the electronic components used for the machine, it is important to mention that a source of 48 V and 10 A was used to power the CL86T driver for controlling the motor, the microcontroller, the Arduino UNO, the microprocessor Lattepanda V1, and the LM2598 stepdown module (this module was used to obtain an output voltage of 5 V). Finally, to obtain the data from the load cell, an HX711 module powered by the microcontroller was used to obtain analog data. All aforementioned components were placed in a metal electrical box as shown in Fig. 2.

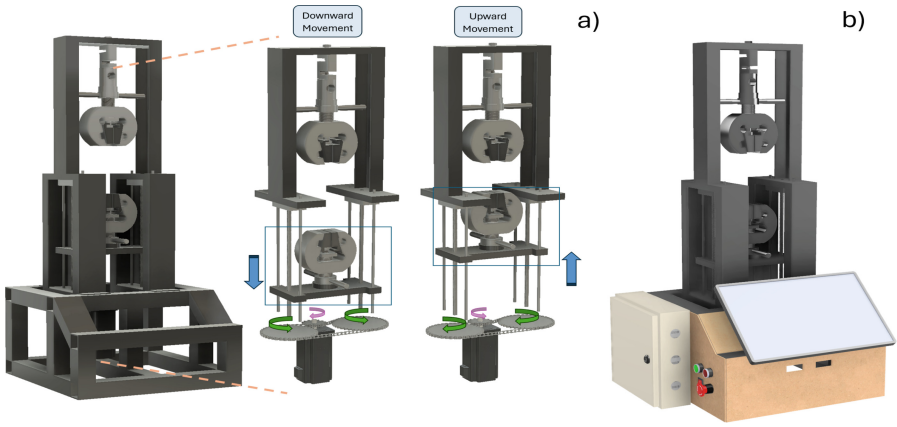

Fig. 1. a) Mechanical components , b) Tensile tesing machine.

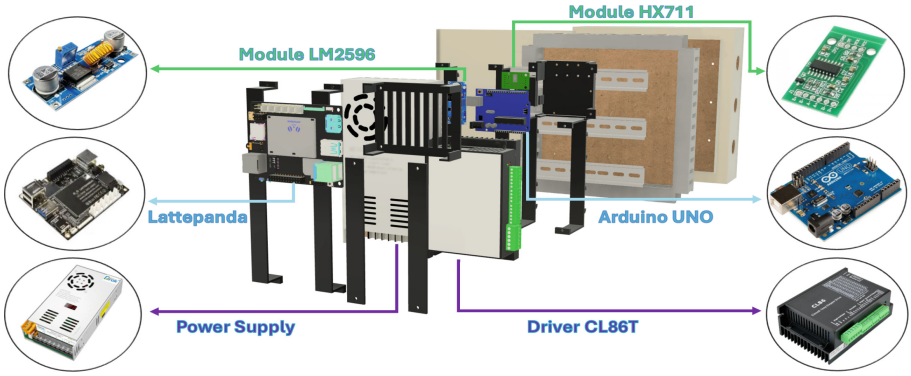

Fig. 2. Electronic components used and their distribution in the dashboard box.

Software Design: For this section, Visual Studio software with C# language was used to create the application in which the process of the tensile test is controlled. Likewise, the Arduino IDE software with C language was used for programming the microcontroller and the microprocessor.

For communication between the aforementioned devices, the I2C protocol was applied, which is a serial communication protocol that facilitates data transfer between integrated circuits, and it is characterized by its simplicity, synchronous operation, and support for multiple devices [32,33].

Referring to the application, this program allows you to choose between two options: testing under the ASTM 638-22 standard and a free mode. In the first option, it is only necessary to choose the type of specimen to be used according to the standard, whether type 2, 4, or 5, and the speed, where you can choose between 50, 100, and 150 mm/min. On the other hand, referring to the free mode, the main dimensions of the specimen and the desired speed must be set.

Furthermore, there is a panel from which the movement of the lower clamp can be controlled manually.

Once the parameters have been configured, the test begins. While the test runs, the stress and deformation values are saved in a vector and plotted in a chart. At the end of the tensile test, the respective results are displayed as an image, and the values are saved in a CSV file. The process flow is detailed in Algorithm 1.

Algorithm 1. Testing process

Input: Choose testing mode (ASTM 638-22 or Free mode)
if ASTM 638-22 mode selected **then**
  Choose specimen type (Type 2, 4, or 5)
  Choose speed (50, 100, or 150 mm/min)
else if Free mode selected **then**
  Enter specimen dimensions and desired speed
  Choose speed (50, 100, or 150 mm/min)
end if
Control lower clamp movement manually if needed
Execute test
Obtain stress and deformation values during the test
Plot stress-deformation curve
Display and save results:
- Display results
- Save stress and deformation values in a CSV file
- Save stress-deformation graph image

Finally, it is important to mention that the machine does not have an extensometer or any deformation measurement instrument. For this reason, it has been decided to estimate the deformation based on programming. This analysis has been carried out by estimating the amount of data obtained through the serial port per minute; in this case, there are 1160 data points. Therefore, the deformation fraction f_δ of the specimen is defined with the expression f_δ = speed/1160. This deformation fraction is the deformation obtained in each iteration of the system. Nonetheless, the total deformation is quantified by the sum of all fractions' deformation.

2.2 Assembly, Functionality, and Validation

Once all design steps were completed, the machine's functionality was tested. Each component of the machine was tested 10 times to ensure correct operation. It began by verifying the correct functioning of the clamps in various types of plastic. Also, it was verified that the machine's physical power button, the pilot lights, and the emergency stop button worked without defects during the machine's operation. Finally, it was verified that the machine control application works without errors or unforeseen stoppages.

Calibration Procedure: Once the machine's behavior was verified, its calibration was carried out. For the calibration of the machine, the concept of the force generated by a spring and its elasticity constant was used, which is a measure of the stiffness of an elastic member or material, quantifying how much force is required to deform it by a certain amount [34]. Therefore, in this case, a spring with a known elastic constant, 5 kN/m, was used to calibrate the load cell of the machine. The spring was placed between the machine clamps. The spring was fixed to the top clamp, and a weighing scale was placed between the spring and the bottom clamp. The prior process is shown graphically in the Fig. 3.

Fig. 3. Graphic representation of spring placement in conjunction with the portable scale between the machine's clamps for calibration.

The objective of using a spring for calibrating the machine was to stretch the spring to a certain deformation and obtain the force being exerted, which has been corroborated by the portable hook scale and also with the equation $F = kx$. F is the force exerted on the spring, k is the elasticity constant, and x is the spring deformation. This F can be transformed into a mass by dividing the force by gravity g as shown Eq. 1 (mass in Kg).

$$w = \left(\frac{kx}{\mathrm{g}}\right) 1000 \tag{1}$$

To find an optimum value of the calibration constant, 10 tests were carried out using the previous process to calibrate the machine's load cell through the microcontroller. Consequently, the calibration constant for the HX711 module in Arduino IDE was modified in each test, in conjunction with the programming to

receive the data from the module, until a similar result was achieved in terms of mass between in the portable scale, the equation, and the calibration program.

2.3 Industrial Application

To validate and show one possible application of the machine, the equipment was used to measure the tensile strength of an industrial plastic strap. Then, the values obtained from the machine were compared with the HT-9112 tensile testing machine from Hung Ta Instrument CO. LTD. The plastic strap specimen was made from polypropylene (PP) with dimensions of 0.82 mm in thickness and 10.4 mm in width. Since the machine used has a different gripper system than the developed machine, the test area differed in the initial longitude between clamps (testing zone, see Fig. 4a). The machine of this work has mechanical wedge grips, in which a specimen of 100 mm longitude between clamps was selected (see Fig. 4b). However, the HT-9112 machine has mechanical roller grips, which make it possible to set the minimum distance between clamps at 310mm (see Fig. 4c).

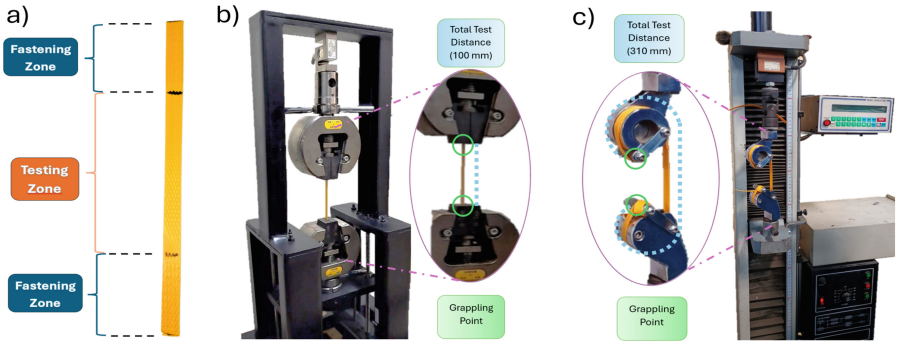

Fig. 4. a) Specimen, b) Mechanical wedge grips, c) Mechanical roller grips.

To obtain a realistic validation, 10 tests were run on both machines. Then, the tensile stress and strain of the specimens were compared to measure the performance of the machine developed. The machine's performance was measured by the percentage of error obtained between the developed machine and the Hung Ta Instrument CO. LTD. machine.

3 Results and Discussion

3.1 Machine Fabrication and Assembly

The fabrication of the structure and the complete assembly of the machine were developed in-house. Figure 1b shows the final machine in detail. As is seen in this figure, the machine has a monitor to manage the test configuration easily

and also to see the stress vs deformation plot during the test. Additionally, the machine has a power button and an emergency stop button, together with pilot lights that reflect the state of the machine, where the green light means normal operation and the red one represents that the process has stopped. Mostly, the process to follow is first to turn on the machine, then place the specimen between the clamps, configure the type of test, start the tensile test, and at the end, save the results obtained. To better understand the machine's functionality, the following link shows a video explaining the operation through a tensile test on a plastic strap: https://youtu.be/_4uhBLEe2eo.

Regarding the mechanism, there were no failures or vibrations on the part of the engine or the transmission chain connected between sprockets. Likewise, the electronic system allowed the motor and the different devices to be controlled for the correct operation of the machine. In addition, the microprocessor and the microcontroller were optimal for establishing communication between them and executing the application to display the results in real time.

3.2 Calibration Results

Concerning the calibration of the machine, the results to obtain an optimum value of the calibration constant are shown in Table 1. As shown in this table, it is possible to see that when the calibration constant is 4.2, the mass obtained in the load cell is 5.13 kg, while the mass measured in the scale is 5.2 kg, and the mass found by Eq. 1 is 5.13 kg. Therefore, the error between the load cell and the scale is 1.36%, while the error between the load cell and Eq. 1 is 0%.

Table 1. Calibration process results.

Test	Calibration constant	Load cell [kg]	Scale [g]	Equation [kg]
1	1	12.56	4.50	4.72
2	2	10.45	3.20	3.11
3	2.5	9.60	5.63	5.78
4	2.7	9.32	4.56	4.32
5	3	89.70	5.63	5.55
6	3.5	8.50	4.50	4.62
7	3.7	8.10	5.60	5.46
8	3.9	7.25	4.25	4.37
9	4	6.11	5.85	5.71
10	4.2	5.13	5.2	5.13

3.3 Application Results

Figure 5 shows an example of the physical experiment carried out using the machine of this work. In this figure, it is possible to see three scenarios of the

test. First, the specimen before starting the test and how it is located (Fig. 5a). Second, the deformation produced during the test by the movement of the lower clamp (Fig. 5b). Third, the breakage of the specimen after a certain time, in which the test ends and the data is obtained (Fig. 5c).

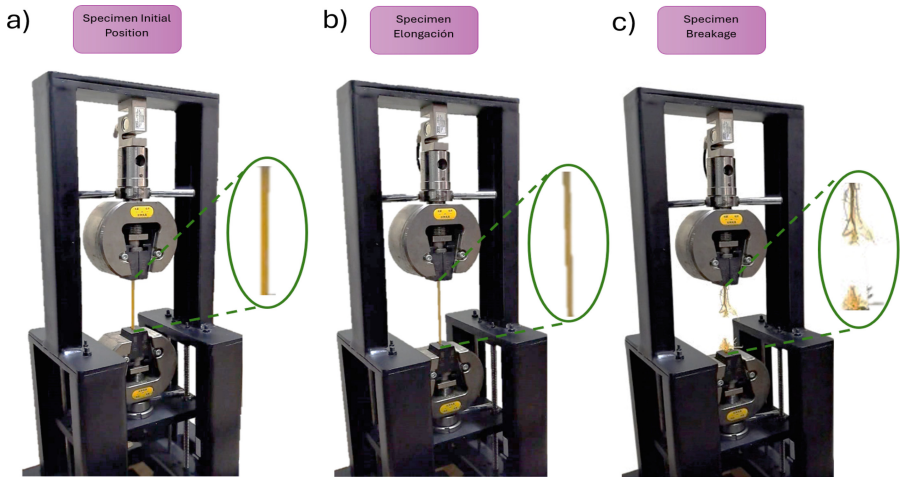

Fig. 5. Example of results obtained experimentally: a)specimen located in the machine, b) specimen elongation during the test, and c) breakage of the specimen.

Table 2 compares the tensile test between the developed and validation machines. In this table, σ is the maximum stress obtained in the developed machine in MPa, representing the material's tensile strength. This strength was transformed to mass w using the Eq. 2, where a is the cross-sectional area of the specimen, mm^2. In the case of the validation machine, there are no values corresponding to the stress because this machine directly measures the mass to tensile the specimen. The mass obtained in both machines was compared. As shown in Table 2, the mass values between both machines are in good agreement. The error in the average values of the mass obtained is 2.46%.

$$w = \frac{\sigma * a}{\mathrm{g}} \tag{2}$$

Table 2 also shows the deformation values of each specimen tested. However, there are considerable differences in the deformation values between both machines. This difference is due to the tensile test in the machines being done with different testing zones in terms of the distance between the clamps. Therefore, to compare the plastic deformation of the specimens, in Table 2, it was also estimated the strain ϵ of each specimen by using the Eq. 3. Where δ is the deformation of each specimen in the different machines expressed in mm, and l is the initial longitude of the testing zone in mm.

Table 2. Comparison of application results between machines

	Developed machine				Validation machine		
Test	σ [MPa]	w[kg]	δ [mm]	ϵ	w [kg]	δ [mm]	ϵ
1	187.29	162.82	29.14	0.291	167.10	69.70	0.224
2	193.95	168.60	29.79	0.298	162.50	70.18	0.226
3	194.54	169.11	28.45	0.285	163.75	67.65	0.218
4	187.37	162.88	28.88	0.288	162.65	71.19	0.230
5	192.80	167.59	28.67	0.287	162.80	67.81	0.220
6	192.35	167.21	26.25	0.263	164.70	67.69	0.218
7	189.20	164.46	28.19	0.282	163.20	69.85	0.225
8	194.84	169.38	29.09	0.291	166.81	68.32	0.220
9	195.17	169.66	27.81	0.278	166.20	75.26	0.243
10	192.37	167.23	29.74	0.297	148.08	66.09	0.213
Average	191.98	166.89	28.59	0.286	162.78	69.37	0.224

$$\epsilon = \frac{\delta}{l} \tag{3}$$

By comparing the ϵ in both machines is possible to evidence that the strain values are close. By Analyzing the average of ϵ, the error of the developed machine compared to the validation machine is equal to 2.17%. This small error may be explained by the difficulty in measuring the initial testing zone longitude in the validation machine due to the roller grips. In this type of grip, identifying the point at which the material plastic elongation is initiated is complex since there is no jaw covering the material and avoiding the elongation. This problem might not exist in the mechanical wedge grips.

4 Machine Cost and Comparison

Table 3 shows the approximate costs of the developed machine, considering the materials, the mechanical and electronic components, the manufacturing and assembly, and the design hours. Joining these expenses, the machine has a final cost of $1,258 USD. Besides, the expected profit to estimate the sale price was added, obtaining a total of $1,908 USD. In this way, the machine's price can be compared to similar machines of the industry [35–38] with a sales price range of around $4,000 USD to $6,000 USD. Therefore, an advantage of around 52.3% to 68.2% is obtained in terms of cost-benefit with the developed machine, which represents more than 50% of savings. Also, considering that these machines are typically imported, incurring additional shipping costs of approximately 25% of the original price, the locally produced machine offers a distinct advantage. It can be manufactured domestically, leveraging local labor, which not only reduces overall costs but also contributes to job creation through the potential for mass

production. In fact, it is a clear innovation within the national territory because this type of machines are not easily found.

Table 3. Table of costs.

Elements	Cost
Mechanical components	$100 USD
Electronic components	$272 USD
Structure	$50 USD
Screen	$80 USD
Clamps	$200 USD
Working hours	$336 USD
Manufacturing Hours	$220 USD
Total cost	$1,258 USD
Expected profit	$650 USD
Total sale price	$1,908 USD

Given the nature of the asset as a machine, it is essential to incorporate a thorough depreciation analysis. In this scenario, considering that the machine is domestically manufactured in Ecuador, an estimated service life of 8 years has been established, with a residual value exceeding 10% of the machine's original cost [39]. These parameters provide the foundation for conducting a linear depreciation analysis, as demonstrated in the following equation [40]:

$$Depreciation/year = \frac{C - S}{N} \tag{4}$$

where C is the original cost of the machine, S the residual value, which in this case has been chosen as $500 USD, and N represents the service life of the machine in years. Applying the Eq. 4 it was obtained a depreciation cost per year by lineal method of $176 USD. Consequently, with this information the estimated depreciation values are presented in Table 4.

Once the following results have been obtained, the depreciation comparison with machines with similar characteristics is shown in the Table 5. The depreciation values per year and the residual value of each one are highlighted following the process and calculations mentioned above.

Regarding the table above, 1 represents the proposed machine, 2, 3, 4, 5 are the machines corresponding to [35–38], respectively.It is evident that as the initial price of the machine increases, the annual depreciation cost proportionally rises. This can be perceived as a market disadvantage, as a machine with a high yearly depreciation cost indicates a substantial reduction in its value over time. Such a steep decline can adversely affect the machine's long-term economic viability and diminish its replacement value, making it less attractive from a financial perspective [41–43].

Table 4. Table of depreciation.

Service year	Machine cost	Depreciation cost/year	Resale value
1	$1,908 USD	$176 USD	$1,732 USD
2	$1,732 USD	$176 USD	$1,556 USD
3	$1,556 USD	$176 USD	$1,380 USD
4	$1,380 USD	$176 USD	$1,204 USD
5	$1,204 USD	$176 USD	$1,028 USD
6	$1,028 USD	$176 USD	$852 USD
7	$852 USD	$176 USD	$676 USD
8	$676 USD	$176 USD	$500 USD

Table 5. Table of depreciation cost comparison between machines.

Machine	Machine cost	Depreciation cost/year	Residual value
1	$1,908.00 USD	$176.00 USD	$500.00 USD
2	$6,503.80 USD	$609.73 USD	$1,625.95 USD
3	$4,197.60 USD	$393.53 USD	$1,049.40 USD
4	$4,600.00 USD	$431.25 USD	$1,150.00 USD
5	$5,300.00 USD	$496.88 USD	$1,325.00 USD

5 Conclusions

The research conducted has yielded a robust mechatronic design and the successful development of a tensile testing machine tailored for plastic materials. The resulting machine demonstrates exceptional precision, with an experimental error of merely 2.5% in determining the tensile strength of plastic straps and an accuracy of 2.17% in measuring material strain. These results underscore the efficacy of the design steps and calibration procedures, validating the machine's readiness for industrial or laboratory utilization. Moreover, the affordability of the developed machine is noteworthy, with a retail price of $1,908 USD, representing a substantial 68.2% cost reduction compared to other industry-standard machines. This affordability aspect enhances accessibility to advanced testing capabilities within both industrial and research settings, facilitating broader adoption and utilization of this technology.

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Optimizing Disaster Preparedness: A Zigbee and Digimesh-Based Approach for Illuminated Evacuation Routes

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Abstract. Natural disasters are increasingly frequent, affecting numerous countries and regions. This study introduces a technological tool aimed at improving energy efficiency and aiding in tsunami evacuations and disaster drills. In addition to complementing existing early warning systems, the tool enhances evacuation processes in coastal areas and serves as a simulation resource for community training.

The research shows that integrating specific technological elements into existing street lighting effectively creates an evacuation route indicator, supplementing physical signage and phone alerts. The solution utilizes a mesh network architecture with end devices connected via the Zigbee protocol and Digimesh topology. Key results include reduced channel interference, minimized data loss, and extended battery life through retransmissions. Signal strength was maintained between −77 dBm and −89 dBm, indicating very good to excellent performance. Sleep mode activation was achieved within 0.077 s, making the system suitable for disaster scenarios. These outcomes were validated in a real-world pilot study.

Keywords: Internet of Things · Natural Disasters · Public Lighting · Smart Cities

1 Introduction

Natural disasters are increasingly frequent and impactful, with a 26% rise in storms, 23% in floods, and an 18% increase in flood-related deaths reported in 2020 [1]. Historical events such as the 2004 Indian Ocean Tsunami, the 2010 Haiti Earthquake, and the 2015/2016 drought in India highlight the severe consequences on human life and economies.

To mitigate these impacts, a robust framework for prevention, public education, and rapid disaster response is essential. Effective evacuation strategies are

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crucial, as demonstrated by [2], who emphasize the importance of timely warnings. The 2011 Japan Tsunami serves as a key example, where prompt evacuation alerts significantly reduced casualties [3]. Japan's Earthquake Early Warning (EEW) system, frequently activated and widely disseminated, is a model for disaster management [4].

Chile, situated in the seismically active Pacific Ring of Fire, is adopting similar strategies, focusing on coastal evacuation alerts and tsunami drills inspired by Japan's successful practices.

This research proposes a technological tool to enhance energy efficiency and support evacuations during tsunamis. By integrating with existing street lighting, this tool aims to serve as a dynamic evacuation route indicator, supplementing traditional signage and alerts. The solution employs a mesh network using the Zigbee protocol and Digimesh topology, ensuring reliable, energy-efficient communication during disaster scenarios.

2 Related Works and Context

Public lighting today is seen as one of the major expenses for municipal administrations due to its high energy consumption and inefficiency. This is because of the lack of information about the current state of public lighting systems, which prevents knowing their consumption, costs, performance, safety, compliance with regulations, and potential for improvement. Scientific research aims to develop a new model for efficient and effective management of public lighting to help transform urban centers into smart cities.

To achieve smart city connectivity in public lighting, it is necessary to review the classification of wireless networks. Depending on the range in meters, wireless networks are classified as WPAN, WLAN, WMAN, and WWAN.

For the development of this work, WPAN networks, which are protocols for short-range communications, will be used. This is relevant because the distance between lamp posts in Chilean public lighting is less than 100 m, and these networks are low-power and cost-effective.

2.1 Communication Protocols for Smart Cities

When choosing a protocol, no priority can be given to one over the other, as each has different applications in different circumstances [5]. For example, Bluetooth is adapted for communication over short distances, while ZigBee is ideally suited for industries where data transfer occurs at low speeds.

Specifically for this work, we will use the Zigbee protocol, IEEE 802.15.4 standard [6], an open standard whose conception began in 1998 thanks to joint research by several companies, including Motorola, Ember, Honeywell, and Mitsubishi. This consortium called the ZigBee Alliance, was motivated by the need for a standard for low-speed communications with low implementation costs and where devices forming part of a network may require low power consumption, functioning for years with just a couple of batteries. It is known for its simplicity, low power consumption, and secure network capabilities.

2.2 Advancements in Mesh Network Protocols

From ZigBee, we find a derivation called DigiMesh [7], a proprietary protocol designed by Digi International. A unique feature of this protocol is that all devices in the network are of the same type, and there is no parent-child relationship. They can route through a mesh network and sleep to optimize energy consumption. It offers various transmission speed options at 900 MHz (10, 125, 150 Kbps) and 2.4 GHz (250 Kbps).

The payload of the frame can be larger, which can improve the performance of applications that send larger data blocks. It uses a simplified addressing method, which improves network configuration and troubleshooting. Protecting nodes in the network is easier and faster than in a ZigBee network, in addition to using industry best practices.

In the study "Performance Evaluation of DigiMesh and ZigBee Wireless Mesh Networks" [7], tests were conducted, measuring performance, round-trip time, received signal strength, and mesh routing recovery time. The experiments show that DigiMesh outperforms Zigbee networks in terms of performance. However, the latter outperforms DigiMesh-based networks in terms of lower round-trip time, higher received signal strength indication, and less time to recover from a node failure. These characteristics make ZigBee a better choice for applications requiring low latency and needing a longer communication range, while DigiMesh-based networks are better suited for high-performance requirements.

2.3 Applications in Public Lighting Systems

In the 2019 International Conference on Science and Systems Engineering (ICSSE) [8], innovative products and components for public lighting are proposed, offering a consumption reduction solution based on an intelligent system of remote measurement and control with GPS/GPRS/4G technologies for the public lighting system. In the article "Design, Deployment, and Evolution of Heterogeneous Smart Public Lighting System" [9,10], a comprehensive discussion is provided on network architectures and communication technologies that could be adopted for intelligent public lighting applications, showing their benefits and drawbacks.

2.4 Integration with IoT Technologies

Further research highlights the application of intelligent lighting control systems [8], integration of IoT technologies [13], and long-distance communication capabilities of ZigBee modules [14]. These studies reinforce the potential for efficient, cost-effective, and scalable solutions in public lighting and disaster management scenarios, ensuring enhanced safety and energy management.

3 Proposed System

The proposed solution utilizes existing street lighting infrastructure, resulting in significant cost savings as no additional posts or luminaires are required. Street

lighting is present in most coastal areas with significant populations, ensuring extensive coverage for any project based on this infrastructure. The luminaires must be equipped with new LED technology, which allows for rapid switching on and off, essential for effective implementation. The system controls the intermittent lighting of each luminaire to create a sequential light pattern, indicating evacuation directions and attracting attention with flashing lights. Additionally, LED lights offer the highest luminous efficiency and lower energy consumption. See Fig. 1 for an illustration of the connected street lighting.

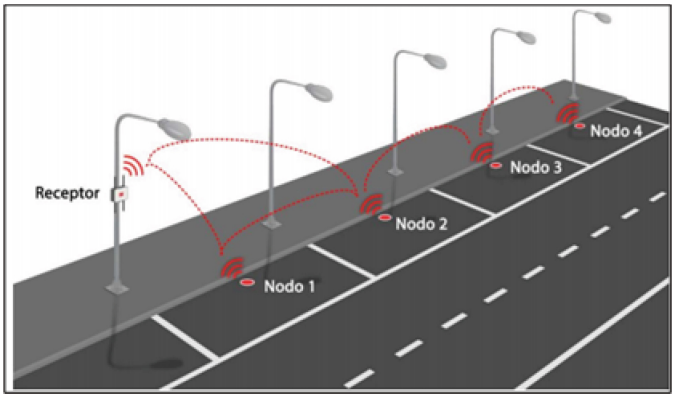


Fig. 1. Connected Street Lighting.

In the event of a tsunami alert in a coastal Chilean city, comprehensive assistance is essential to guide citizens to designated safe locations. Current communications inform the population of procedures and evacuation routes, supplemented by simulations to verify their effectiveness. Additional measures will greatly minimize the impact on citizens.

Implementation requires minimal intervention in luminaires and low-cost devices, ensuring logistical feasibility. An IT system will control the synchronous on/off switching of each luminaire, creating a virtual path for evacuation. These luminaires will be centrally managed through a mesh network, using radio frequency signals for command distribution and signal repetition.

Prototype

The system requires adding an XBEE 3 radio frequency receiver to each luminaire to control their on/off switching through centralized programming using the Zigbee/Digimesh communication protocol, allowing coordinated commands to be sent so that the luminaires function together as a signaling route indicating the direction of population evacuation.

For our case, we will use the central area of Valparaíso city (see Fig. 2). The yellow points indicate a configuration of evacuation routes with directions that

go from the coast towards the interior of the city, in this case, from Avenida Errázuriz to Urriola and Almirante Montt, surrounding Cerro Concepción.

Fig. 2. Valparaíso City Center Map.

Digimesh is the communication protocol between XBee devices. Through it, a central device can communicate with the devices in each luminaire to transmit the signal instructing when to turn each luminaire on and off (see Fig. 3). Moreover, they have synchronized cyclical sleep, allowing all nodes to sleep, saving energy and enabling devices to work with batteries.

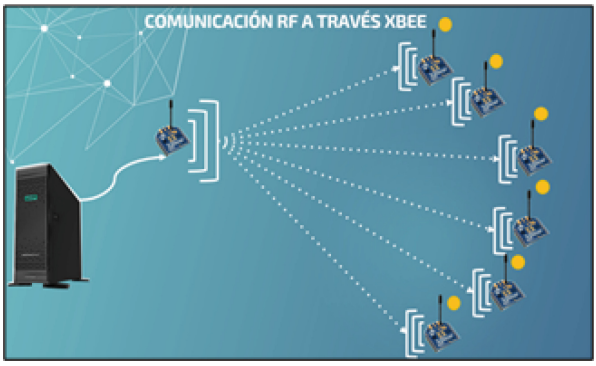


Fig. 3. RF Communication via XBee.

MicroPython is the programming language that will be used to develop the code to manage and control the complete configuration of the system, identifying each luminaire and allowing the control of when to activate it, as well as programming routes, intermittence, activation start and end times, and so on.

The chosen topology is a mesh, which allows information to travel through multiple paths without a central node. If one node fails, it does not affect the

network. All nodes within range of each other are connected, resulting in overlapping edges.

3.1 Implementation Results

This work should allow for the implementation of illuminated, dynamic, and centrally controlled signage.

A field distance test was conducted, verifying that the maximum range is 100 m when communicating with 3 nodes and their respective coordinators, separated at distances similar to those of street lighting posts, without connection issues.

To test the Sleep mode, which allows the device to enter a low-power state when no activity is detected, the configuration was set to SM (Sleep Mode) = 4 (Async. Cyclic Sleep).

The parameter SM corresponds to the capability of putting the DigiMesh communication module to sleep, consuming very little battery. In this case, mode 4 allows the module to sleep and wake up in a cyclic but unregulated manner. The developed code will define the time it remains awake and asleep. The Digimesh solution is 25% more expensive than the Zigbee solution.

3.2 Challenges

The conditions of the Sleep mode need to be established, considering that the solution could remain dormant for extended periods. Testing of the Sleep mode will need to be planned, as it will be the initial state of the system. Regular functionality tests will be required and can be carried out during low-scale simulation drills.

A geographical survey of the pilot area will be necessary to determine the number of street lighting posts, the average distance between them, building heights, distance from the coastline, and safe evacuation zones. This will provide more concrete cost figures for the solution.

3.3 Technical Development

The prototype development aims to create a model to validate that the developed algorithm works as required. When a Tsunami signal or evacuation drill is activated, the illuminated route will be activated, with different lighting patterns depending on whether it is day or night (i.e., luminaires are off during the day and on during the night).

The components used in building the prototype are defined (see Fig. 4).

The mobile device simulates the emergency activation, in our case, the Tsunami alert or evacuation drill. Only a device capable of internet browsing is needed to access the page where the emergency is activated.

The light sensor detects the luminaire's status, whether it is on during the night or off during the day.

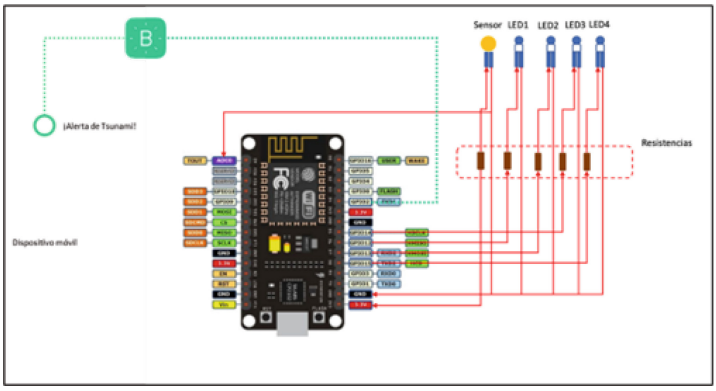


Fig. 4. Prototype Components.

The LED simulates each luminaire. For this prototype, four luminaires are considered.

The integrated circuit corresponds to the board containing the programming code, the web server, and the hardware components' connections (sensors, LED, resistor). ESP8266 WiFi board.

The programming code enables the operation of the illuminated route.

Once the components are connected and the code is developed, the prototype is completed as shown in Fig. 5.

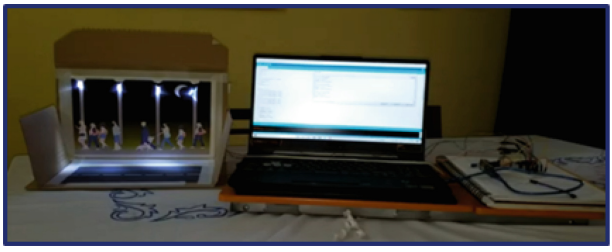


Fig. 5. Prototype Implementation.

To perform the on-site analysis of the solution, the city of Valparaíso, Chile, specifically the route between Urriola and Almirante Montt streets, was visited.

During the site visit, the current conditions of the luminaires, which will be part of this work's analysis, were reviewed.

Unfavorable conditions were observed for installing the luminaires, such as damaged luminaires, lack of sensors, and designs that deviate from the standard.

It was also evident that the buildings in the selected area are of low height, 2 to 3 floors, which benefits wireless communications, presenting fewer obstacles to connectivity.

In the selected area, a walk along the entire route of interest was made to georeference each existing street lighting post using the Mobile Topographer tool (see Fig. 6).

Fig. 6. Georeferencing Tool.

Once the luminaires were georeferenced, they were overlaid on the map of the streets under analysis using QGIS, along with official information layers of the flood area in case of a 6-meter Tsunami wave, evacuation areas and routes, and meeting points for evacuation (see Fig. 7).

Fig. 7. Street Lighting Location, Flood Area, and Evacuation Routes.

The distance between each street lighting post was obtained through the on-site review and georeferencing.

Based on the on-site review, it is concluded that conducting on-site surveys to verify existing conditions is crucial to consider field variables and ensure the implementation's success.

4 Discussion

In the official information provided by the equipment manufacturer [11], the variables necessary for the proper functioning of the solution are highlighted, including DATE RATE (transmission speed), INDOOR/URBAN RANGE (maximum indoor distance), OUTDOOR/RF LINE (maximum outdoor distance), TRANSMIT POWER (transmission power), and RECEIVER SENSITIVITY (input signal).

To conduct the service tests, we will utilize the proprietary and free tool, a cross-platform application to interact with Digi's RF modules through a graphical interface. It includes new tools that facilitate the installation, configuration, and testing of the XBee® RF modules [12].

The spectrum analysis allows us to measure the noise level for each channel within the frequency band of the radios, with the purpose of selecting the optimal communication channel (dBm/channels). The dBm (decibels-milliwatt) is a unit of measurement primarily used in telecommunications to express absolute power using a logarithmic relationship. It is defined as the power level in decibels relative to a reference level of 1 mW. The dBm value at a point, where we have power P. See Eq. 1.

$$P(dBm) = 10log\frac{P(mW)}{1mW} \tag{1}$$

The spectrum analyzer facilitates the real-time measurement of energy levels across multiple radio channels, utilizing graphical and statistical tracking to aid in optimal configuration selection. This process mitigates high interference channels, thereby enhancing network reliability, preventing data loss, and extending battery life. As depicted in Fig. 8, the graph illustrates the noise levels of all RF channels. Each channel is represented by a bar indicating the current noise level, with two markers denoting the maximum (green) and minimum (red) noise levels. Additionally, a blue line represents the average noise level across all channels. The spectrum analysis continuously updates the noise levels for each channel until the analysis is concluded or halted.

Mathematically, the spectrum analysis is related to the Fourier Transform (FT), which provides a relationship between the frequency domain of signals and the time domain. See Eq. 2.

The integral acts on t, so the frequency f must be treated as if it were a constant. In fact, the exponent $-j2\pi f$ is a constant. If the original function exists between two real values a and b, the integral's primitive is solved between those real values.

$$\int_a^b x(t)e^{-2\pi ft}dx \tag{2}$$

For the range, we set up the loopback for the local and remote modules, sending 100 packets with a delay of 1 s. We measure the signal strength (RSSI), which is a relative measure of the energy strength of a radio signal, obtained

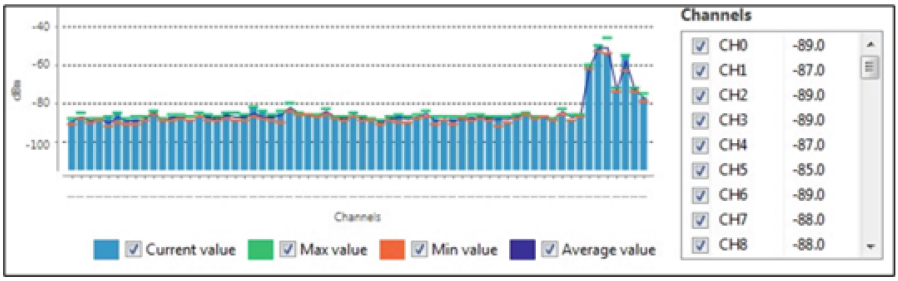


Fig. 8. Spectrum Analysis.

by a wireless network interface card. As shown in Fig. 9, it is observed that as the modules move away, the signal strength decreases, while the reception percentage remains high. At some point, the signal begins to be lost, and the reception percentage starts to drop when the RSSI falls close to -100 dBm. With this test, it is possible to predict the signal range loss and ensure that all nodes are at a safe distance with a margin of safety. It is also possible to check how much signal is absorbed by a wall, building, or other objects. All data is presented in graphs, including the indicator of local and remote received signal intensity, the number of packets sent and received, and a line graph showing these values over time. See Eq. 3.

$$RSSI = PEM - LFS + LT + (LT - x) \tag{3}$$

where:

- PEM = Transmitted Power
- LFS = Free Space Loss
- LT = Transmission Loss (obstacles)
- $LT - x$ = Transmission Loss up to the calculation point.

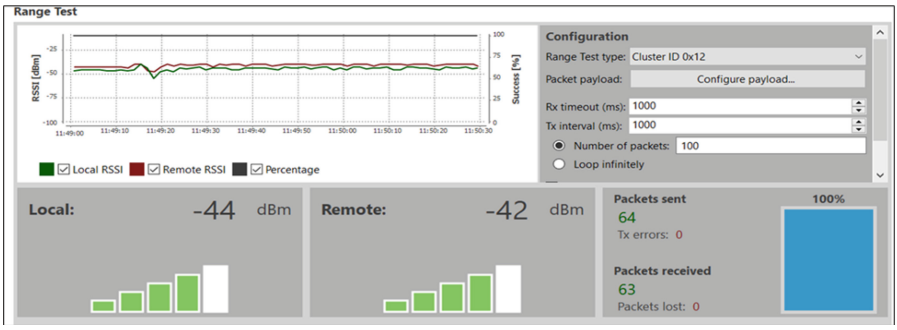


Fig. 9. Range.

The transfer test measures the transfer ratio between two radio modules in the same network, along with the instantaneous and average transfer rate (kbps/time) (Refer to Fig. 10). The instantaneous transfer rate is shown with a light blue area, and the average transfer rate is shown as a dark blue line. The instantaneous transfer ratio is calculated every 250 ms or whenever a packet is sent.

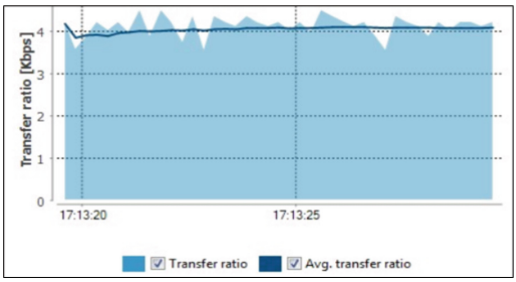


Fig. 10. Performance.

The data transfer rate is the speed at which a certain amount of information is transferred over a specified period of time. To perform the mathematical calculation, the first step is to convert the units so that the file size and download speed are expressed in bits or bytes with the same prefix (kilo, mega, giga, or tera). See Eq. 4.

$$V = fracDT \tag{4}$$

where:

- D = Amount of data
- T = Transfer time to obtain
- V = Speed or transfer rate

The transition to sleep mode allows measuring the time it takes for the device to enter a low power state when not performing any activity (milliseconds/distance). We will use the synchronous sleep mode (synchronous sleep), see Fig. 11. The synchronous sleep function allows all network nodes to synchronize their suspension and activation times.

All synchronized cyclic rest nodes enter and exit a low-power state at the same time, forming a cyclic rest network. The nodes synchronize by receiving a special wireless packet called a synchronization message sent by a node acting as the sleep coordinator.

During normal operation, the sleep coordinator sends a synchronization message as a transmission to all nodes at the beginning of each activation cycle. This message contains synchronization information and the activation and deactivation times of the current cycle.

All cyclic suspension nodes (SM = 8) that receive a synchronization message remain awake during the activation time and then go into rest mode during the specified suspension period.

For our case, we will use synchronous cyclic sleep, where an XBee in synchronous cyclic sleep mode sleeps for a programmed time, wakes up simultaneously with other nodes, exchanges data, and synchronization messages, and then goes back to sleep. While sleeping, it cannot receive serial or wireless data.

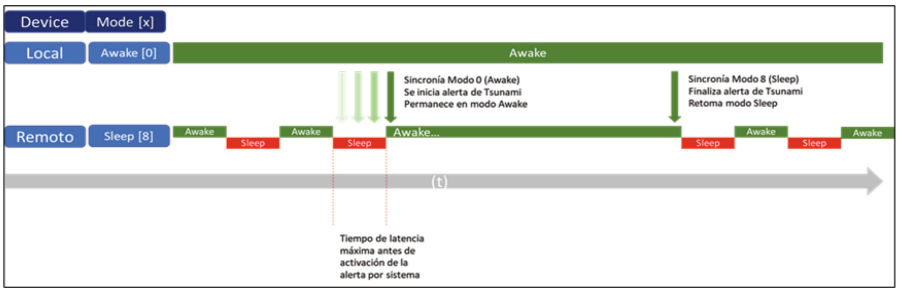


Fig. 11. Synchronous Sleep Mode.

With the spectrum analyzer, the energy levels in the radio channels were reviewed in real-time, along with sources of radio noise (see Fig. 12). This graph allows us to choose the channel with the best signal strength when configuring the central and remote nodes.

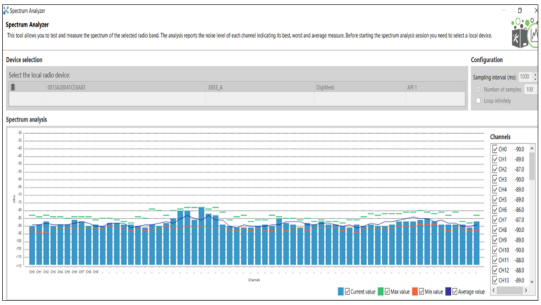
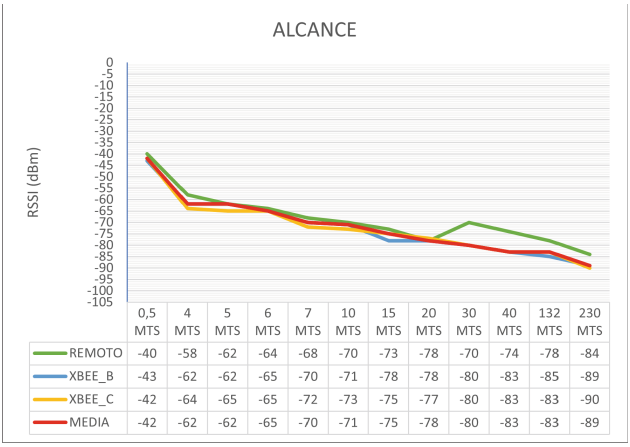


Fig. 12. Channel Spectrum Analysis.

The spectrum analyzer was crucial for network implementation, enabling real-time review of energy levels and noise sources across 16 radio channels. This allowed optimal configuration of central and remote nodes on channels with the best signal strength, ensuring reliability, preventing data loss, and extending battery life through retransmissions. Additionally, it aids in problem-solving by identifying unwanted noise sources during real-time channel reviews.

Field tests were conducted to estimate signal range loss and ensure nodes maintained a sufficient safety margin, with an RSSI above -76 dBm for excellent signal or between −89 and −77 for very good signal (see Fig. 13). The data collected was used to calculate average signal intensity.



	0,5 MTS	4 MTS	5 MTS	6 MTS	7 MTS	10 MTS	15 MTS	20 MTS	30 MTS	40 MTS	132 MTS	230 MTS
REMOTO	-40	-58	-62	-64	-68	-70	-73	-78	-70	-74	-78	-84
XBEE_B	-43	-62	-62	-65	-70	-71	-78	-78	-80	-83	-85	-89
XBEE_C	-42	-64	-65	-65	-72	-73	-75	-77	-80	-83	-83	-90
MEDIA	-42	-62	-62	-65	-70	-71	-75	-78	-80	-83	-83	-89

Fig. 13. RSSI/Distance/Average.

The average was used for the nearest meter ranges of the sample with the lamp post in the field, to determine each post's RSSI quality.

The range tests validate signal quality at different distances. Twelve tests were conducted from 0.5 to 230 m, and it was observed that although the RSSI quality decreases with increasing distance, data transmission remained successful up to 230 m. The average RSSI obtained was used to extrapolate the values to the sample (distances) of lamp posts obtained in the field. It was concluded that the distances between lamp posts (ranging from a minimum of 18 m to a maximum of 97 m) ensure an RSSI quality from excellent to very good, guaranteeing a successful installation in the field.

To measure the total time it takes for the sleep mode to be activated from the central node, validation tests were conducted in the field. See Table 1 and Fig. 14. The data obtained were used to calculate the time average.

The average data for the total sleep mode activation time was applied to the real distance table of lamp posts raised in 1. Using the average time for 15 m (each distance was divided by 15 and multiplied by the time for this distance), it was shown that the total activation time did not exceed 8.6 s for 1,600 m.

Synchronous cyclic sleep tests validate the total activation time of remote points when receiving an alert signal to activate the illuminated path. Five tests were conducted from 0.7 to 15 m, and it was observed that the activation time increases with distance. At 15 m, the activation time was measured to be 0.077 s. The average time in seconds obtained was used to extrapolate the values to the

Table 1. Sleep Mode Activation Time

DISTANCE (m)	TIME 1 (s)	TIME 2 (s)	TIME 3 (s)
0.5	0.07779	0.07241	0.07352
7	0.07834	0.07920	0.08036
15	0.07855	0.07721	0.08718
DISTANCE (m)	**TIME 4 (s)**	**TIME 5 (s)**	**TIME 6 (s)**
0.5	0.07628	0.07645	0.07628
7	0.07976	0.08299	0.07976
15	0.07392	0.07060	0.07721

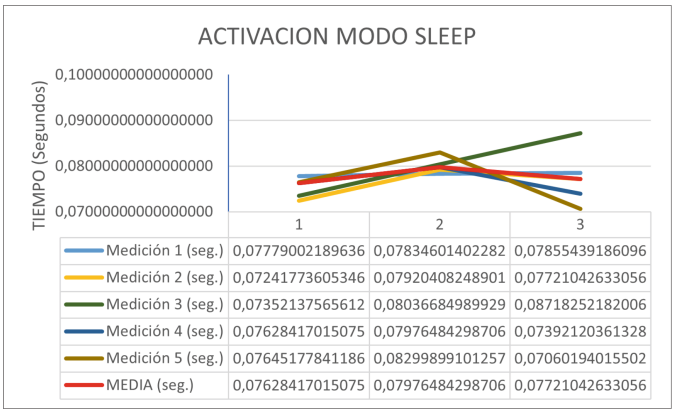


Fig. 14. Sleep Mode / Distance / Average.

sample (distances) of lamp posts obtained in the field, and it was concluded that the total activation time (1,600 m) takes 8.5 s.

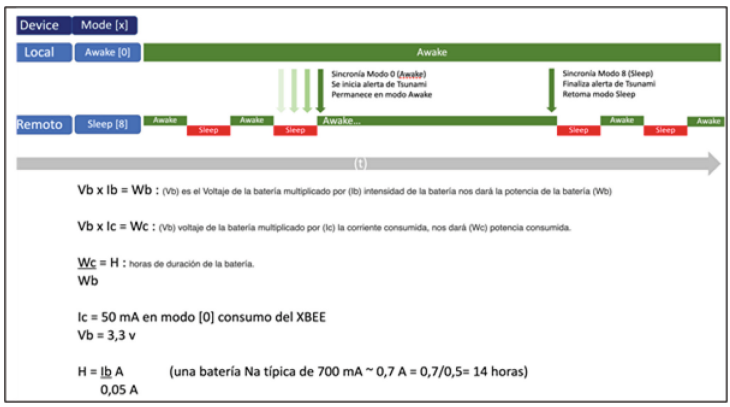


Fig. 15. Synchronous Sleep/Battery Consumption.

On the other hand, the synchronous cyclic sleep must be carefully configured to achieve the greatest battery autonomy if required, and also to ensure that it is activated in case of a tsunami alert (see Fig. 15).

5 Conclusions

The conclusions from this project address the research problem of lacking technological tools to support evacuations and drills for natural disasters, specifically tsunamis, in coastal areas using existing infrastructure like street lighting. Chilean coastal regions are highly vulnerable to tsunamis triggered by nearby or distant earthquakes. Therefore, timely information is crucial for residents and visitors to evacuate flood-prone areas, follow marked routes, and reach safety.

This work provides a complementary solution to existing methods, ensuring timely alerts, efficient evacuation routes indicated by the street lighting system, and guiding people to safe areas. The project's objective was to design a technological tool that enhances existing measures (such as signage, sirens, and text messages) by supporting evacuation drills and real tsunami alerts, thereby helping citizens evacuate efficiently and safely.

Leveraging existing street lighting infrastructure makes the 'Illuminated Evacuation in Natural Disasters' project easy to implement, cost-effective, and quickly beneficial for citizens. However, for the tool to work successfully, it should be as automatic as possible, integrated into the national alert system organically and without human intervention. Additionally, there is a need for public awareness and training on tsunami-related topics and the development of drill execution plans to ensure that the tool is a valuable asset during actual evacuations.

The Digimesh communication protocol facilitates the interconnection of existing street lighting via WPAN, enabling devices to alternate between SLEEP and alert modes to optimize energy consumption. It is recommended to conduct further testing with approximately 50 devices (representing 50% of the street lighting in Valparaíso) to refine timing configurations for enhanced energy efficiency.

The solution is designed with a flexible, scalable, and failure-resilient mesh topology, ensuring that the failure of a single node does not compromise the network's functionality. This inherent flexibility and resilience of the Digimesh protocol ensures system continuity, even in the event of node failure.

The prototype demonstrated that the solution is effective, simple, and cost-efficient. The implementation successfully coordinated the lighting sequence, benefited from the protocol's resilience, and proved economically viable for larger-scale deployment due to the low unit cost.

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Application of Design Thinking in the Product Ideation Phase: Use of Agile Methodologies

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Abstract. The transition to higher education presents challenges for incoming students. In a demanding academic environment, autonomy emphasizes fostering collaboration within the student community. This approach enhances interaction and integrates experienced students' knowledge to support peers, aiming to improve academic performance. The study is centered on developing software prototypes for a digital platform to facilitate the intermediation of contacts among students, primarily for scheduling tutoring services. An Action Research strategy was employed, using focus group techniques to actively involve participants in the project. This method, supported by Design Thinking, utilized iterative phases that generated valuable insights, leading to the creation of several prototypes tailored to the real needs of users. This iterative process not only highlights the significance of each phase but also explores how they collectively enhance product software development, focusing on ideating and refining concepts based on the perspective of future users. The testing of these prototypes met user expectations, demonstrating the effectiveness of the Design Thinking approach. This contributed to satisfying user needs and promoting collaboration through interaction with the focus group. Moreover, adopting the Kanban project management method allowed for practical and efficient workflow management. Consequently, this article not only promotes methodologies that facilitate the ideation of a digital product designed to address a real-world need but also underscores how project management can be an integral ally in development, ensuring effective integration.

Keywords: Product Ideation · Design Thinking · Project Management

1 Introduction

In universities, students are required to demonstrate significant autonomy in their studies. Occasionally, additional support through tutoring from university peers who have greater knowledge or expertise in a specific area proves to contribute to a better student performance. According to Casanova [1], establishing support systems to help students who are less prepared to acquire the necessary technical competencies is seen as a

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possible measure to fight dissatisfaction with academic performance. After research, it was not possible to find in the consulted literature the impact that a centralized student contact network has on dropout rates or academic failure in higher education. Thus, as prescribed by Saunders et al. [2], a survey was conducted in September 2022 among university peers at the University of Minho, Portugal, from various fields of study. Based on the forty valid responses obtained, it was found that over 70% of the students believed that being part of a tutoring system with peers would positively impact their grades, and more than 70% of respondents were willing to financially compensate their peers for tutoring sessions.

The creation of a digital platform that assists in mediating contact between two profiles of students—those seeking study support and those willing to provide it—could contribute to increasing the tutoring rates in higher education, which is currently less than 10% [3], due to the significant costs of tutoring in this type of education. In the survey conducted, over 80% of respondents expressed interest in the envisioned digital product. Besides fostering academic success, the students' justifications indicated that the existence of such a centralized platform could enhance academic networking, facilitate the integration of new students experiencing a transitional phase on a new student environment and being tested against the demands of the new academic context, and promote knowledge sharing, resulting in a beneficial relationship for both parties. For the tutee, the benefit would be gaining desired knowledge, and for the tutor, it would be earning extra income by providing a service. Given this identified need, Project Management (PM) was used and applied as support for Product Development [4]. Although they have distinct focuses, the tasks of both are closely linked, complementing each other [4]. In increasingly complex environments and the need to adapt product development to the constant changes in the desires of potential users and the market, there is a growing need to establish a flow between user demand and product discovery through hypothesis generation and testing. For this, Agile Methodologies were applied in planning, backlog management, control, and organization of all the work necessary for the creation of the digital product.

The ideation of the digital platform was supported by the DT methodology, which utilizes iterative phases, where various methods can be applied that have proven to be quite useful [5]. It is important to note that there is a plethora of methods, and throughout the investigation performed, a critical analysis was adopted in their application. The challenge was to experience and select some of these methods used to solve similar problems, highlighting the product discovery phase.

2 Literature Review

2.1 Product Development

The product lifecycle management is a model that describes the various phases a product goes through, from its conception to its withdrawal from the market. Each phase of the lifecycle has its own characteristics, challenges, and objectives [6]. Various authors discuss the different stages inherent in the continuous process of product lifecycle management [7]. Product Development, as the name suggests, focuses on the team's efforts to create, and develop the product through prototypes and various tests. Theodore Levitt

was the first to introduce this concept in the 1960s, highlighting the importance of the product lifecycle and describing five phases that the product must undergo: Product Development, Introduction, Growth, Maturity, and Decline [8].

2.2 Project Management in Digital Product Development

Project management is defined as the application of knowledge, skills, tools, and techniques to project activities to meet their requirements [9]. In digital product development projects, the scope is often not fully definable early on, leading to a high degree of uncertainty. Agile methodologies accommodate this by enabling short development cycles, adapting to constant changes through continuous evaluation and feedback [9].

In recent decades, Kanban has emerged as a significant methodology in software development, described as an approach for incremental and evolutionary changes [10]. It involves a set of practices for managing project development, focusing on continuous value delivery and ongoing improvement. Some authors [11] have acknowledged Kanban as crucial for managing workflow and minimizing waste in software environments.

2.3 Design Thinking

Design Thinking (DT) is a methodology that enhances the resolution of complex and unclear problems through a human-centered approach [12]. There is no single process surrounding the DT process. Like its definition, it is not singular and has been observed differently by various authors, with no authoritative, singular, and standard process. One of the most used methods is the Stanford school model, composed of five phases—Empathy, Definition, Ideation, Prototype, and Testing [13]. These are characterized by being iterative, dynamic, non-hierarchical, marked by flexibility, and the absence of a mandatory predefined phased sequence.

3 Research Methodology

3.1 Action Research

Action Research is a methodology designed to develop solutions for organizational problems through a participatory, collaborative, and iterative approach that integrates various forms of knowledge [2]. The purpose of its application is to promote organizational learning aimed at producing specific practical outcomes [2]. It is applied within a specific context and develops through various stages and iterations, starting with the Diagnostic phase, where problems are identified, followed by the Planning and Execution of certain actions, culminating with subsequent Evaluations of these actions [2]. These actions are introduced in cycles, as depicted in Fig. 1. The first cycle begins with all these phases. Based on the evaluation results, informed by the participants' feedback, a new cycle emerges that allows for the adjustment of the diagnosis and problem definition to better reflect the reality and new understandings of the context, followed by new planning of a set of actions to be executed and concluding with another evaluation of the new results obtained. This process repeats with each new cycle and begins with

a more informed re-evaluation and ends with an increasingly detailed evaluation of the new actions considered, enabling continuous adaptation, and learning through the active participation of the organization's members.

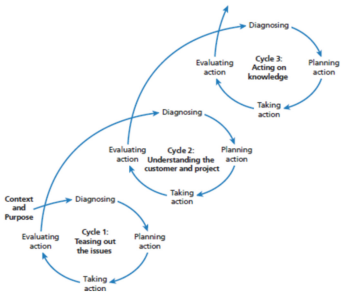

Fig. 1. Action Research cycles [2].

Greenwood and Levin [14] view participation as a critical component, highlighting that this methodology is intrinsically linked to a social process in which the researcher collaborates with other members in an active and democratic manner, to ensure that the solutions conceived and developed are relevant to the context of the problem itself.

3.2 Focus Group

Focus groups are a form of group interview that capitalizes on communication between research participants to generate data [15].

In the selection of a focus group, it is important to select participants who are familiar with the problem to be explored, as well as to include members with different profiles and genders to enable the discussion of the topic from various perspectives [16].

Thus, the planning and selection of the focus group followed a meticulous process. As a digital platform being developed for the academic environment, the search was limited to individuals of different genders and ages who were higher education students. Since the initial plan was to design the product using the University of Minho as a case study, the group was restricted to students who had an academic relationship with this institution. Subsequently, tutor and tutee characteristics were identified, facilitating the categorization of each participant into future user profiles of the platform, as described in Sect. 4.2.

Regarding the size of the group, it should be sufficient to collect enough data to reduce potential uncertainties in handling responses, but at the same time not too large as to impact response time and subsequent data collection. In this work, a contact with eleven individuals was made continuously. Students from a variety of courses were considered to avoid bias related to existing academic course patterns.

Interaction varied between individual approaches, such as the initial interview phase and the testing of functional prototypes, and group sessions, to foster discussion and convergence of different perspectives in support of decision-making, such as in validating the

prioritization of opportunities or the most critical assumptions. Furthermore, the opportunity to interact with the mentioned group also served as additional validation of the work performed, confirming whether the perceptions derived from interactions with them and presented in the application of the methods, were aligned with their expectations. These checks were essential to proceed to subsequent phases of the research.

4 Application of Action Research Through Design Thinking for Product Ideation

4.1 Action Research Through Design Thinking

Action Research focuses on continuous and interactive processes in seeking solutions to a specific problem through active collaboration of various organization members.

As previously mentioned, DT centers on the real needs of the individuals involved in a particular context to conceive and develop suitable solutions, using an iterative process of prototyping and feedback.

Katoppo and Sudradjat [17] suggest combining the methodology of Action Research with the DT, where the collaboration between both is seen as an effective strategy in developing participatory practices.

In this work, DT and its iterative phases were integrated into the continuous cycles of Action Research. The initial phase of Action Research, the Diagnostic phase, for example, was incorporated by the DT into the initial Empathy phase, where the focus was to identify, investigate, and explore the observed problem. Next, the Planning phase included the Definition stage, guiding the subsequent phase of the process. The Action phase corresponded to the Ideation and Prototyping phases, transforming the concepts defined in the previous plan into practical prototypes available for evaluation. Finally, the Evaluation phase synchronized with the Testing phase, whose feedback was essential to understand the necessary adjustments and to validate the effectiveness of the solutions in front of the end users.

4.2 Empathy Phase

This phase focused on exploring the needs of students, identifying the academic challenges they face, and gathering their feedback through a set of open-ended questions. The responses provided input for the creation of personas and the development of empathy maps. These tools aimed to provide a solid foundation for understanding the true needs of the future product users, evaluating their reported experiences, and understanding the emotions and challenges they face during their daily study processes and their interactions with a tutoring service, aligning these insights with the work being developed in creating future potential solutions in the subsequent phases.

Individual interviews were chosen to gather qualitative data and ensure that the responses provided by the interviewees were not limited. The target audience for the interviews was outlined into two types of student profiles that could associate with the platform as users. One profile was aimed at students who needed educational support, to obtain a tutoring service, who would interact with the platform from the perspective

of tutees. Another profile was directed towards potential tutors, intended to provide a tutoring service, and who had some interest and prior experience with similar services.

The questions were categorized in a structured guide with open-ended questions covering personal, social and demographic aspects, as well as exploring emotional aspects of the study process, including students' expectations, frustrations and routines.

All questions were externally validated to ensure their clarity, relevance, and comprehensiveness. This process helped refine the questions, making them more understandable and pertinent to the interviewees, thus laying a solid foundation for more productive and insightful interviews. Additionally, to align the responses with interviewees' expectations and confirm their understanding by the researcher/interviewer, a follow-up validation with the interviewees was conducted to secure their consent and agreement with the transcribed responses. Based on the responses obtained and the response patterns observed in the interviews', detailed personas were developed that represented archetypes of the end-users, ensuring a holistic understanding of students' perceptions, encapsulating a set of characteristics such as the demographic and social, needs, motivations and behaviors of the students. Figure 2 exemplifies one of the two persona profiles created, in this case for the tutor.

An empathy map was also developed, providing a graphical view of the emotions, thoughts, and behaviors of the students, based on the need to deepen the understanding obtained from the interviews, aiming to consolidate the qualitative data acquired and provide a more complete representation of the identified profiles, proving to be an essential step to synthesize the various behavioral and emotional traits of the identified profiles. The empathy map for the tutor profile is represented in Fig. 3.

Fig. 2. Persona for the tutor.

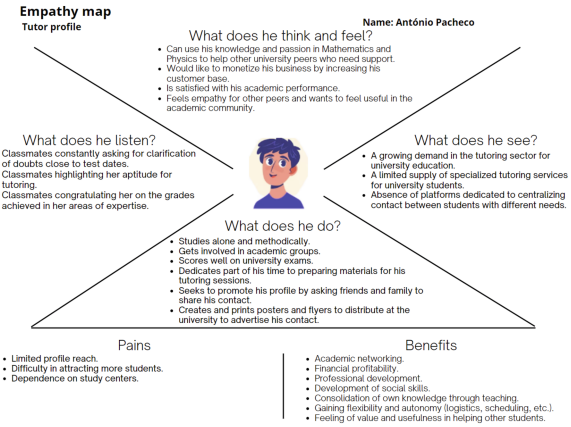

Fig. 3. Empathy map for the tutor.

4.3 Definition Phase

This phase focused on defining the problem that needed to be solved. That is, following the work done in the previous phase, where the aim was to understand the perspective

of the students and their needs, the focus shifted to gaining a clear understanding of the problem, to gather the minimal conditions necessary for developing possible solutions in the next phase.

The Definition began with the creation of a Lean Canvas, a method based on the Business Model Canvas, commonly used in the embryonic phases of PD [18]. This method allowed efforts to be concentrated on defining, at a high level, the various requirements needed in the pillars, represented in Fig. 4.

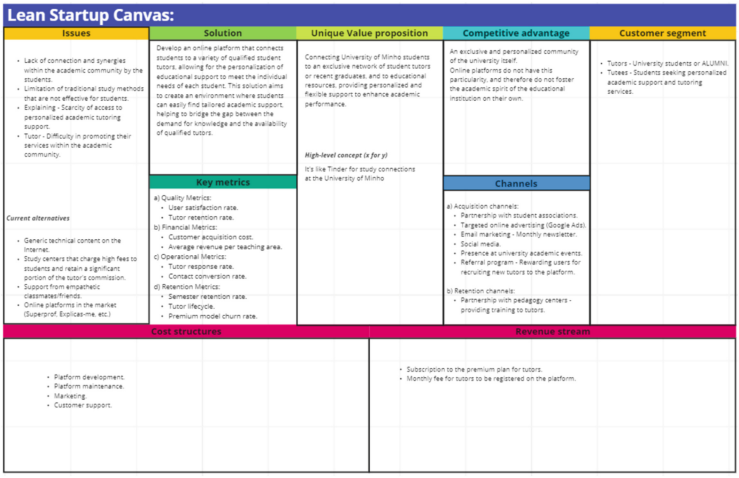

Fig. 4. Lean Canvas.

Another methodology used was the Opportunity Solution Tree (OST). While the Lean Canvas provides a structured and simplified overview of the business model, the OST complements this view by detailing a set of scenarios, challenges, and potential opportunities identified for exploration [19]. The integration strengthens the holistic understanding of the project, enriching the strategic analysis and defining the context to be worked on in subsequent phases.

The OST is a visual tool and hierarchical structure that allows product teams to envision the necessary path to follow, considering a defined outcome. Based on the identification of the product users' needs, it explores clear and actionable opportunities for idea generation, to create potential solutions or implement specific improvements in the products and services being developed. Although the number of hierarchical levels is not strictly fixed, generally it has five levels: outcome, opportunities, solutions, assumptions, experiments [19]. Figure 5 presents the OST applied in the Definition phase, identifying the first two levels, the first referring to the outcome and the second to the opportunities identified.

4.4 Ideation Phase

The various opportunities identified were prioritized by the RICE method [20], with the focus on generating potential solutions for the three most critical opportunities obtained.

Efforts were made to generate a diversity of solutions, reflecting a wealth of perspectives, exploring different possibilities, as represented in Fig. 5 on the 3rd level.

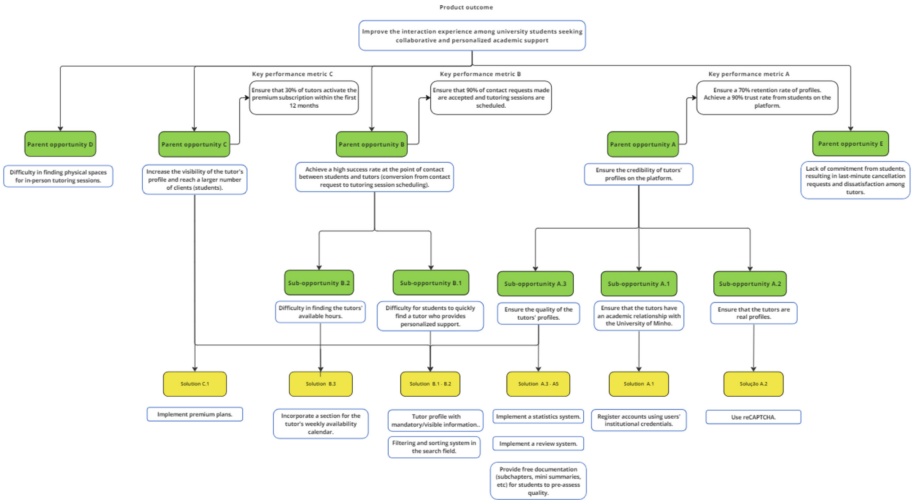

Fig. 5. Opportunity Solution Tree: 1st, 2nd and 3rd levels.

For each solution, there is a set of underlying assumptions that need to be tested and validated. These are fundamental hypotheses that support the strategies outlined for each "mother opportunity" or "sub-opportunity". Validating these assumptions allows for the mitigation of risks and increases the confidence level that the proposed solutions effectively meet the demands of the end users. For this purpose, Story Mapping was used to visualize and organize the solutions in a logical and structured manner, based on a narrative to identify the various elements involved, as well as the necessary steps involved in the envisioned solution. By structuring the steps, a set of assumptions of various types are defined, providing a comprehensive and detailed view of the necessary actions and the assumptions being made, as shared in Fig. 6.

Since it is common to generate an extensive list of assumptions for a single solution due to resource and time constraints, it is essential to prioritize and assess which key assumptions need to be tested and are critical to the success of the product being developed. In this regard, a matrix was used that relates the degree of importance and certainty for each assumption. Critical assumptions are those that have a higher degree of importance but are less evident, indicating a greater need and priority to be tested.

4.5 Prototyping Phase

The next phase was dedicated to transforming the abstract concepts, derived from ideal solutions and premises identified in the OST, into tangible and testable prototypes. This stage is essential as it is through this that ideas begin to take shape, allowing for a practical and direct evaluation of the proposed solutions. Prototyping serves not only to visualize

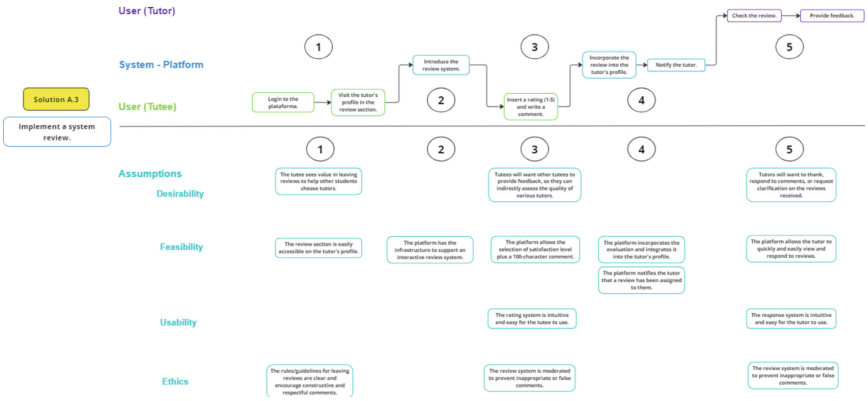

Fig. 6. Story mapping for solution A.3: implement a review system.

solutions in a realistic context but also as a vital tool to allow for the identification of improvement points, refinement of concepts, and validation of solutions with users in a quick and economical manner, before committing significant resources to the final implementation of the product [21].

It is important to note that prototyping is, by nature, an iterative phase. This means that prototypes are subject to constant adjustments and improvements, based on feedback collected during the user testing phase. This cycle of feedback and refinement continues until the prototype reaches a level of maturity and satisfaction that is deemed adequate by the stakeholders involved in the process [22].

To effectively conduct this phase, a methodological approach focused on creating detailed processes was adopted. The aim of this approach was to structure and visualize the various usage scenarios associated with the proposed solutions. This establishes a solid foundation for creating prototypes, allowing for the exploration of a wide range of possible user interactions with the system. Different use cases were mapped using the draw.io software [23], creating a clear and detailed representation of how users might interact with the system in various situations, anticipating different paths that students may take when using the proposed solutions on the platform.

This structured approach to solution design, combined with prototype creation, significantly facilitated the transition from paper ideas to interactive and functional prototype models using Adalo software [24]. These prototypes served not only to validate the proposed solutions with users but also to iteratively refine and improve these solutions continuously. Since the objectives of each type of user registering on the platform are distinct, it was essential to design two different models of the platform, as the visualization of content, functionalities, and interaction with the product varies, whether the user is a tutor or a tutee. Figure 7 presents an example of prototypes, where the first provides information about each tutor's profile, academic background, teaching methods, availability, and some statistics. The second prototype presents a sample of documents that the tutors provide on the platform. The third prototype shows the reviews, and the last prototype features the introductory video.

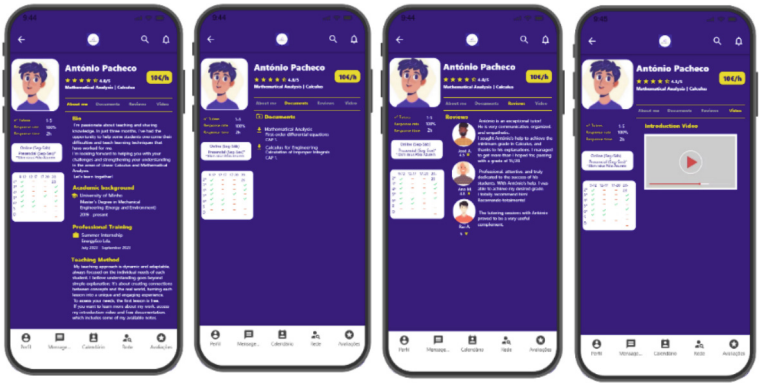

Fig. 7. Prototypes for Solution A.3: implement a review system.

4.6 Testing Phase

After completing the first version of the platform prototypes, the next phase focused on defining clear, objective criteria to guide the testing evaluation, particularly the validation of the most critical assumptions—those marked with high importance and low evidence. A detailed validation strategy was developed, along with rigorous criteria to determine whether the key hypotheses were validated or needed adjustment. This process ensured a methodical and organized testing approach, allowing accurate analysis of the proposed solutions' effectiveness. Thus, the process ensures that the prototype features matched user expectations, not just meeting but exceeding identified needs, thereby enhancing the product's relevance and efficacy. The validation conditions are presented in Table 1.

Table 1. Validation of test for solution A.3: implement a review system.

Method	Critical assumptions	Validation conditions
Interviews	The tutors will want to thank or request clarifications on the feedback received	80% respond affirmatively
Usability tests	The response system is intuitive and easy for the tutor	90% post the general comment without doubts/questions
	The response system is intuitive and easy for the tutee	90% complete the evaluation process without doubts/questions

Subsequently, attention was focus on the dynamics of testing, allowing for an overall evaluation of the platform. This approach was bifurcated, as in the initial interviews: separate tests were carried out for tutees and tutors previously selected in the focus group. The focus group, as explained in Sect. 3.2, was composed of eleven members, each interacting with the version of the platform that suited them. The tests took place on the participants' mobile devices, covering a wide range of functionalities, from creating

an account and logging in to using specific tools such as chat, search, calendar, payment, and profile evaluations. Every possible action on the platform was tested by possible users. Each user's actions were meticulously monitored through observation and directed questions, gathering real-time feedback, and recording user reactions to interactions, with the purpose of assessing the impact each action and button had on the experience and perceived value.

Two phases of testing were carried out, with the first phase aimed at collecting points for improvement and the second phase aimed at assessing whether the test conditions presented above were met. The record of this first stage is schematized through the customer journey mapping executed for each profile. Figure 8 shows an example for the tutor profile. It is important to note that this method was not intended to analyze all the possible functionalities of the platform, but only the main ones that are relevant to incorporating value centered on the user experience.

Fig. 8. Story mapping for the tutor.

The detailed analysis of feedback enabled the identification of improvement opportunities, which were systematically catalogued in a Refinement Backlog. Consequently, the prototypes were iteratively improved, addressing the highest priority points before moving on to less urgent issues. The prototype revision was not limited to incorporating the detected improvements but also involved revisiting the processes initially established in the previous phase, with the aim of refining and adjusting these processes considering the new information obtained, as already explained. This enhancement phase proved crucial to ensure that the proposed solutions were even more precisely aligned with user needs and expectations. After adjustments and implementation of identified functionalities and improvements, new tests were made, intending not only to validate the changes made, but also to test the critical premises under real usage conditions, thus maximizing the reliability and acceptance by users. The results were successfully achieved, as the validation conditions were ensured, demonstrating significant improvements in user

experience and platform usability, under the designed prototypes, promising indicator for the success and acceptance of the conceived and implemented solutions.

5 Use of Kanban

The implementation of a Kanban board was explored to manage the work presented, highlighting the effectiveness of a simplified system in improving PM. Initially, the board was configured with five main stages: Backlog, To Do, In Progress, Review, and Concluded [10]. To control workload and maintain quality, Work-In-Progress (WIP) limits were imposed on the "In Progress" and "Review" columns, with adjustments made to reduce the number of tasks in progress from four to three.

Furthermore, a bottleneck was identified in the "Review" column, which often depended on external approval. To address the issue, an "In Approval" column was added to separate tasks that required external intervention, thus optimizing the workflow. The use of color codes also facilitated the visual identification of the project phases, with each one corresponding to a specific phase. Figure 9 presented the resized Kanban Board.

The application of the Kanban method proved to be an enriching practice, providing effective management and facilitating the visualization of project progress. The simplicity of the system proved to be essential, focusing on functionality rather than complexity. The ability to adapt to changes and the limitation of WIP proved crucial for efficient PM.

The experience highlighted the importance of advancing tasks rather than accumulating them, promoting well-being and motivation throughout the project. The adopted approach reinforced the "less is more" principle, avoiding complicating the system with extra low-value columns. This study underscores the importance of flexible and adaptable management, crucial for effectively responding to demands and changes during this investigation.

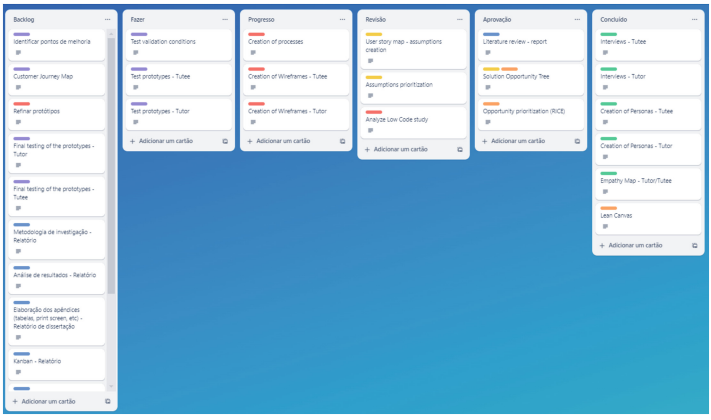

Fig. 9. Kanban board.

6 Conclusions

Throughout the developed work, efforts were made to conceptualize the digital product, an educational platform, using a user-centered methodology that promoted interdisciplinary collaboration, supporting the creation of a product adjusted to market needs. The DT methodology, characterized by its iterative and empirical nature, allowed for deep immersion in the search and identification of potential users' needs and expectations regarding the envisioned product. To this end, the case study began by defining the problem to be solved, based on direct and collaborative contact with the focus group, divided into two distinct profiles of students, which enabled the conception and ideation of potential solutions that were applied, tested, and validated in functional prototypes. These prototypes underwent real usage scenario tests through direct interactions and feedback cycles with the target audience, not only confirming the viability of the proposed solution but also allowing for precious refinements, ensuring their effectiveness, and approximating the initial product version to what the market intended and demanded. Furthermore, the adoption of a focus group was equally important in validating the work done using the applied methods at each completed phase, ensuring an external validation that reinforced the quality of the process and deliverables.

Regarding the objectives proposed, this approach was completed with PM, and specifically with the integration of the Kanban method, which facilitated efficient management of the workflow and respective interactions throughout the various DT phases. This instilled a culture of continuous improvement and adaptive flexibility, based on resizing the Kanban board and limiting the amount of work imposed at each stage, notably by the WIP, with the aim of improving workflow and work performance. The value of simplicity, agility, and adaptive capacity is not only limited to the application of this case study but also offers a universal dimension of wide applicability in PM, which can be replicated in any context and product.

Thus, the expected results for this investigation were duly achieved. The first result, delivering medium-fidelity prototypes, was largely met. Indeed, not only several prototypes were produced reflecting different use cases of the platform, but the level of detail presented was greater than planned. That is, the product prototypes achieved were of high fidelity, exceeding initial expectations. As for the second result, conducting a critical analysis and a sizing of the Kanban board, the sizing was achieved through a careful evaluation of the method's application.

Moreover, it should be noted that, although it was not a goal due to resource and time constraints, no technical computer developments were carried out on the platform, resulting only in the creation of functional and interactive prototypes.

From a future perspective, it may prove to be interesting to develop the product in its real form, not just through the creation of functional prototypes, and consequently integrating an evaluation of the performance of a real implementation in the market.

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Intelligent Monitoring System for Construction Sites

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Abstract. The construction industry continues to face significant challenges in ensuring the safety of workers on construction sites. Recognized as one of the most dangerous work environments, construction sites still report high accident rates despite significant safety efforts. This paper presents a new personnel monitoring system on construction sites with the primary goal of improving safety levels and significantly decreasing the incidence of work accidents. The proposed system is an IoT hardware/software platform based on a geo-fencing system and a Deep Learning model that performs inferences on images acquired from the construction site. Specifically, key functionalities include accurate counting of workers in monitored areas and verification of the presence of personal protective equipment by each worker, while also detecting unauthorized personnel. Rigorous real-world testing has demonstrated the feasibility of the system, especially in terms of real-time operational effectiveness. The results obtained were encouraging to plan further interesting developments on the topic of construction site safety.

Keywords: IoT · Deep Learning · Decision Making

1 Introduction

Over the past decade, numerous research studies have focused on digitizing construction sites with the goal of reducing accidents and safeguarding workers' health and safety [1]. This change has spurred a transformation of practices in the construction industry, traditionally based on conventional methods, toward the adoption of advanced technologies such as the Internet of Things (IoT) and artificial intelligence (AI). However, selecting suitable technology for safety management in construction sites demands a thorough understanding of the site's unique characteristics, specific safety risks, decision-making accuracy, implementation requirements, and potential constraints.

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The aim of this study is to introduce a hardware/software IoT platform designed for ensuring:

- the presence and proper usage of Personal Protective Equipment (PPE);
- the prevention of access to restricted and/or work areas by unauthorized individuals, such as external personnel or those not outfitted with PPEs;
- the geo-location of staff within designated areas of interest via geo-fencing.

Specifically, the system comprises an IoT network featured by three main components:

1. a video surveillance system to count the people and check whether workers are wearing PPEs in the monitored area of interest;
2. a detection system for geo-referencing (geo-fencing) and verifying the presence of authorized persons in the monitored area;
3. a remote IoT platform dedicated to data ingestion and summary data visualization through alerts and dashboards.

In more detail, the first component consists of cameras to count the people in the monitored area and transfer images to an edge computing module that runs a Deep Learning model to verify the presence of PPEs, such as helm and vests. The second component is characterized by wearable tags on workers' vests, allowing for the tracking of entries and exits from the common work area, as well as corresponding tracking. If unauthorized and/or unequipped personnel with PPEs are detected, an IoT gateway connected to both the edge module and the geo-fencing system transmits telemetry to an IoT platform in order to report alerts and allow the visualization of summary data on Web dashboards, usable by authorized users, such as those responsible for safety at the construction site.

Therefore, the goal of this paper is to describe the system in its entirety and verify its performance through both offline tests and real-time testing on a real construction site. Specifically, the project included an initial design phase in which a Deep Learning model for the recognition of PPEs was trained using an online available dataset. Concurrently, images were captured on a real construction site and, after a period of observation, the Deep Learning model was tested offline on the acquired images. Finally, a test of the complete system was conducted on a real construction site.

Consequently, the paper is structured as follows: Sect. 2 describes the state of the art derived from the literature review; in Sect. 3 the system architecture is described, then the training and testing phases of the Deep Learning model are detailed; eventually, the explanation of the experimental setup and the results obtained are explained in Sect. 4.

2 Related Work

The integration of various IoT technologies has significantly improved the monitoring of workers' risk conditions on construction sites for health and safety

analysis [14]. This improvement is primarily achieved through wearable sensing devices [2] and intelligent tracking systems [15,17,37]. Recent studies have demonstrated the use of IoT technologies in developing alarm systems for construction sites. These systems are designed to produce indicators that identify potential hazards and facilitate immediate actions to prevent accidents [29,38]. Additionally, IoT-based applications in safety management systems include real-time monitoring of personnel and the construction site environment [6], with a particular emphasis on wearable sensing devices and location tracking sensors [25]. Moreover, automated control systems for PPE have been developed, enabling simultaneous monitoring, location tracking, and alerting of improper PPE usage [35], as well as identifying workers in hazardous zones [16]. Recent research [11] has revealed that construction site workers utilize wearable tools to gather data on temperature, health status, humidity, air quality, heart rate, and location, which is then securely transmitted through IoT gateways for further analysis.

Beyond IoT, another digital technology extensively employed in managing health and safety on construction sites is Computer Vision (CV). CV's capability to detect, recognize, and track the movement of objects, as well as their interactions, through video footage is invaluable [19]. Specifically, CV leverages Deep Learning algorithms for real-time detection of PPE, a research area that is rapidly evolving as evidenced by recent literature [5,18,22,23,32]. Various AI models have been developed to verify PPE usage, such as helmets and vests, utilizing datasets comprising thousands of images [23]. Furthermore, a novel hybrid approach combining deep learning with geometric analysis has been formulated to identify improper PPE usage [5].

Further research is focused on developing algorithms for tracking multiple workers within the camera's field of view using Machine Learning methods [24,30,34]. For instance, the study in [30] implemented four distinct tracking techniques to monitor workers: density averaging shifting, Bayesian segmentation, active contours, and graphical cuts. In another approach, the authors in [27] employed a hybrid method combining monitoring and detection to locate construction workers. This method primarily identifies new entities and adjusts the tracking region in cases of significant displacement, providing the trajectories of each entity across frames. Additional studies have explored artificial vision techniques for health and safety monitoring in construction [10], examining unsafe behaviors from both technical and practical perspectives, such as the detection of safety devices, camera positioning, and viewpoints. Moreover, a range of computer vision algorithms has been developed to identify workers not wearing harnesses [8]. The authors in [28] proposed a novel computer vision-based framework for detecting unsafe actions and monitoring behavior on construction sites.

A research study [33] suggested the use of color-coded "construction hardhats" as key tracking objects to distinguish different personnel on construction sites, such as workers, supervisors, engineers, etc. The proposed method involves a three-stage process: human recognition, hardhat recognition, and 3D

localization. Additionally, a prototype system for proactive safety management and real-time alarm on construction sites has been developed, based on UWB real-time tracking technology, which implements a control logic that exploits localization data and implements proactive virtual fence logics to test in real time whether a worker is about to access potentially dangerous predefined areas [3].

The work in [20] made it possible to evaluate the failure to use a protective helmet, using artificial vision techniques applied on videos captured from construction sites: this was achieved by isolating mobile workers and/or construction personnel from the scene captured using a new motion detection algorithm and a human classifier and detecting the hardhat in the identified region of interest. While the authors in [12] used the KCF algorithm to continuously track targets to identify specific violations in order to develop an intelligent security monitoring and early warning system and classify the detected violations and timely send the information to the responsible person.

A review of the literature on the potential for adoption of IoT technology and artificial intelligence in the field of construction site security reveals that research in this area is very much alive and is an indispensable need for construction companies. Since there is still no legislation on the topic, the proposed applications are mostly experimental. Therefore, the aim of the present work was to integrate two main functionalities present in the analyzed works, namely, that of PPEs detection and that of geo-localization of workers.

3 The Proposed Approach

In this section, the system architecture is described in Sect. 3.1. Then, the training and testing phases of the Deep Learning model are detailed in Sect. 3.2.

3.1 System and Software Architectures

The architecture of the proposed intelligent monitoring system is depicted in Fig. 1. The worker position detection and video surveillance systems carry out three primary tasks:

1. **Data Acquisition**, involving periodic collection of workers' locations for geo-fencing and images of the working area to be monitored;
2. **Data Processing**, involving edge computing for counting people in the working area, checking the presence of unauthorised people and the proper PPE usage;
3. **Data Transmission**, so as to send updated information to the IoT Platform via the MQTT protocol using an IoT Gateway.

The remote IoT platform handles the storage of the received information and enables the data visualization through a Web Application accessible to the end user (e.g., security manager). In greater detail, the position detection system is characterized by a kit featured by four anchors to establish the perimeter for

geo-fencing and a certain number of wearable tags. The kit utilizes the Two-Way Ranging (TWR) protocol to ascertain the positions of the tags [4]. The anchors, fixed in position, serve as reference points for the geo-fencing system. Consequently, it was imperative to assign coordinates to each anchor before initiating tag position calculation. Among these six tags, one functions as the Master Tag, which is connected to the IoT gateway through a Micro-USB cable. This Master Tag wirelessly communicates with other TAGs, which are integrated into the workers' vests and within its range, to determine their locations. The remote TAGs compute their positions autonomously and require only batteries for operation. The Master Tag then relays this positional data to the IoT gateway. On the other hand, the video surveillance system continuously monitors the area of interest using cameras. Taking advantage of Deep Learning algorithms, it processes the captured images and updates the relevant information to be transmitted to the IoT platform. This process includes verifying the number of workers present, ensuring each worker is outfitted with the required PPE such as helmets and vests, and confirming their correct usage (i.e. a helmet not being properly fastened). Additionally, the output from these algorithms provides a way to track and timestamp the information generated by the video surveillance system. More in detail, the video surveillance system captures frames through bullet cameras, transmits them to an edge computing module (e.g., NVIDIA Jetson Nano), and processes them using YOLOv7. This enables the detection of workers and their protective gear.

In order to show how the system works at a high level, a flowchart describing the operation of the software architecture is shown in Fig. 2, where the following is observed.

- From the Data Acquisition and the subsequent Data Processing two counters are obtained, respectively, C_t and C_p; the first is the number of people equipped with TAG, while the second is the count of people by camera;
- At the same time, a check is performed on the presence of unauthorised personnel and on PPEs; in particular, if $C_t = C_p$ and all those present are wearing PPEs, Data Acquisition and Processing is resumed, otherwise the following step is performed.
- The timestamp T_s, the number of people not equipped with PPEs N_{np}, the number of people not equipped with vest N_{nv}, the number of people not equipped with helm N_{nh} and the number of unauthorised people N_{un} are evaluated and a telemetry containing all these updated values is transmitted to the IoT platform, then resumed with Data Acquisition and subsequent Processing.

3.2 Training and Testing of the Deep Learning Model

Data processing is performed through Edge Computing and, as far as the processing of the images acquired by the cameras is concerned, it employs a Deep Learning model trained on a dataset specifically created for PPE detection problems.

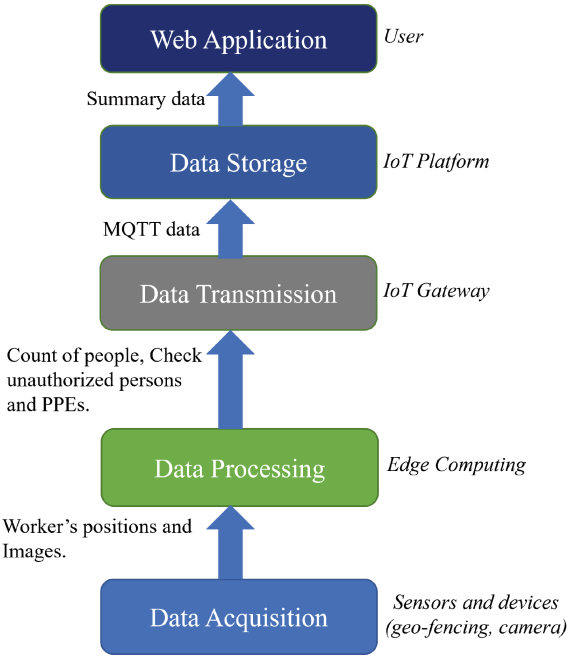

Fig. 1. Monitoring system architecture.

In more detail, for the training of the model, the open-source dataset in [9] was used, containing images representing realistic scenarios typical of construction sites, with workers wearing helmets and protective vests. It comprises images annotated with objects belonging to eight different classes: four for protective helmets (blue, white, red, yellow), one for safety glasses, one for the vest, one for recognizing a person's head, and one for recognizing a person. For the purposes of this project, having different classes for different helmet colors was redundant, so it was decided to consolidate these into a single class to simplify the readability of the results. Thus, the images are annotated with objects belonging to the following classes: 'person', 'helm', 'vest', 'glass' and 'head'. Furthermore, given the theoretical improved performance compared to other frameworks [21,36], YOLOv7 [31] has been used instead of the models proposed in [9], mainly based on YOLOv5.

Training and testing of the Deep Learning model were performed in the Google Colab environment. In particular, the training time was characterized by 100 epochs completed in 1224 h. The metrics used for validating the performance of object detection models are typically precision (P), recall (R) and the mean Average Precision (mAP). In particular

$$P = \frac{TP}{TP + FP}, \tag{1}$$

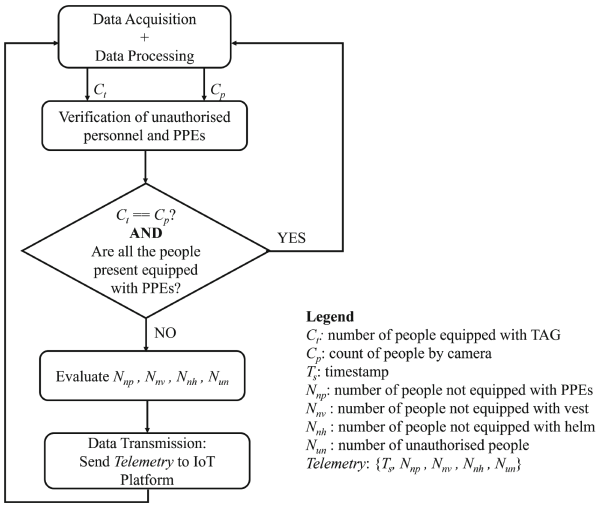

Fig. 2. Flowchart that describes the software logic.

$$R = \frac{TP}{TP + FN}, \tag{2}$$

where TP (True Positive) is the number of objects correctly identified, FP (False Positive) relates to objects that are incorrectly identified, and FN (False Negative) pertains to failing to correctly identify an object.

Defined the Average Precision (AP) for a class c as

$$AP_c = \int_0^1 p(R)\, dR, \tag{3}$$

where $p(R)$ is the function that describes precision as a function of recall R, the mean Average Precision mAP across all classes is the average of the APs calculated for each class

$$mAP = \frac{1}{|C|} \sum_{c \in C} AP_c, \tag{4}$$

where $|C|$ is the number of classes.

Table 1 shows the results obtained on the test set. This set is based on 340 images, while 1700 images were used for training.

Furthermore, the performance can also be observed through the confusion matrix shown in Fig. 3, which displays the overall accuracy of object classifications. Specifically, the accuracy percentages of various classes compared to all others are evaluated. For example, 95% of the 'helm' class is correctly predicted, while 4% is evaluated as 'background', not belonging to any class. For the 'vest' class, 5% is evaluated as 'person', 10% as 'background', and 86% correctly as 'vest'.

The model thus tested on the dataset available online was then validated in the real environment, as will be discussed in Sect. 4.

Table 1. Performance indicators of the model.

Class	Instances	Precision	Recall	mean Average Precision
glass	99	0.72	0.69	0.76
head	156	0.91	0.81	0.87
helm	694	0.91	0.92	0.94
person	931	0.95	0.83	0.94
vest	454	0.88	0.88	0.91

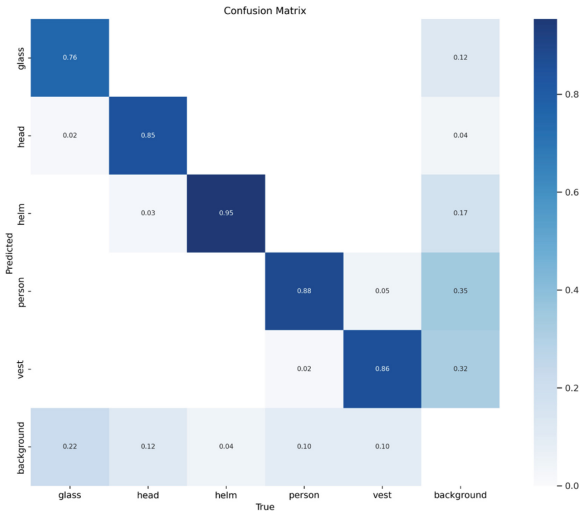

Fig. 3. Confusion matrix.

4 Results

In this section, the explanation of the experimental setup is presented in Sect. 4.1. Furthermore, the results obtained following the initial on-site data acquisition phase are presented, namely, during the offline validation and real-time testing described in Sect. 4.1.

4.1 Experimental Setup

In order to verify the correct functionality and applicability of the proposed system, the experimental setup has been performed considering the entrance area of a construction site. This area covers dimensions of approximately 16 m x 5 m. The anchors of the geo-fencing system has been strategically positioned at the four corners of the monitored area. Coordinates has been determined through a self-calibration procedure provided by the system's software. The camera has been optimally positioned to accurately cover the area defined by the geo-fencing system. The edge computing module devoted to the images processing is a NVIDIA

Jetson Nano connected to the camera via Power-over-Ethernet (PoE), while the IoT Gateway is based on a Raspberry Pi 4 board.

In particular, three phases were considered for experimentation, described below:

- Initial on-site data acquisition phase;
- Offline phase of software integration, tuning adjustments, and testing and validation;
- Final phase for on-site real-time testing.

In more detail, the initial data acquisition phase involved the acquisition of images (at a rate of 10 FPS) and geo-fencing data (at a rate of 1 s), which were stored locally on the edge computing module and the IoT Gateway, over a two-month period (March and April 2023). In particular, the system was configured to be active only during working day hours (8 a.m. to 5 p.m.).

After completing the initial phase, offline testing and validation of the collected data were undertaken. The objectives were twofold: first, to assess the performance of the Deep Learning model with images captured in real-world scenarios; second, to refine and optimize the software design, ensuring seamless integration of geo-fencing and PPE detection functionalities, along with the coordination between the IoT Gateway, the IoT Platform, and the Web Application. Furthermore, for the experimental setup, the chosen IoT Platform is the open-source version of ThingsBoard. This selection is based on its well-documented environment and proven performance capabilities, as substantiated by the findings in [7,13,26].

In conclusion, the final phase was devoted to on-site real-time testing to thoroughly evaluate the performance of the proposed monitoring system, with a specific focus on engaging end-users in the context of occupational safety.

4.2 Offline Testing and Validation

The acquisition phase allowed for the execution of offline analysis on images recorded over a period of two months. In particular, following pre-processing, over 200.000 images were used for testing on the Deep Learning model.

Table 2 presents the results achieved on the acquired test set. The trends obtained mirror those observed during the post-training testing phase (see Table 1). In fact, the values of Precision (P), Recall (R), and mean Average Precision (mAP) show little deviation from the ones obtained previously, confirming lower accuracy in recognizing glasses (possibly due to their transparency) and values exceeding 80% for all other class-related metrics.

In more detail, the 'person' class exhibits the highest precision, suggesting that the model is highly effective in correctly recognizing individuals. The 'helm' class shows the highest recall, indicating that the model excels at detecting the majority of its instances within the test data. The mAP values range from 0.72 for 'glass' to over 0.9 for 'person' and 'helm.' Higher values indicate that the model consistently detects the classes at various threshold levels, providing a

good balance between precision and recall, and it appears that the model is particularly proficient at detecting 'person', 'helm', and 'vest'.

In any case, the overall performance of the model, as indicated by the mAP values, is quite high for most classes, suggesting that the model is generally reliable in accurately detecting and classifying instances within these categories.

Table 2. Performance indicators of the model during offline test.

Class	Instances	Precision	Recall	mean Average Precision
glass	15328	0.68	0.65	0.72
head	50256	0.90	0.79	0.85
helm	152369	0.89	0.90	0.91
person	206873	0.92	0.80	0.92
vest	168984	0.84	0.85	0.88

For the offline data analysis concerning geo-fencing, it enabled the establishment of a strategy to first finalize the software related to Data Acquisition and Processing, and then to emulate transmission to the IoT platform as depicted in the flowchart in Fig. 2. More specifically, the analysis facilitated the adoption of an asynchronous transmission mode, that is, based on updating two counters C_t and C_n. This update occurs according to the logic described in the flowchart of Fig. 4, which represents a detailed view of the "Data Processing + Data Acquisition" block shown in Fig. 2.

Subsequent integration tests were conducted in the laboratory between the IoT Gateway and the Thingsboard IoT platform to finalize the setup of the environment to be used for the real-time testing phase. In this regard, both tests to verify the real-time performance of the software running on the Edge module and the IoT Gateway and transmission tests to determine the minimum time that can elapse between one telemetry and the next were performed.

Specifically, the maximum time to update the two counters C_t and C_p is 190 ms, of which 90 ms to process the data stream from the geo-fencing system and the remaining to execute the Deep Learning model. Moreover, the time required to package the data in JSON format and transmit the telemetry to the IoT platform is below 1 ms, while the minimum time that can elapse between one telemetry and the next is 1 s, which, in the considered context, is deemed acceptable for detecting a group and/or a line of people entering the monitored work area.

4.3 On-Site Real-Time Testing

This phase allowed for the testing of the platform in its entirety on a real construction site in Battipaglia (Salerno, Italy). The system was operational for a month, enabling the verification of its performance in a real-world scenario. The

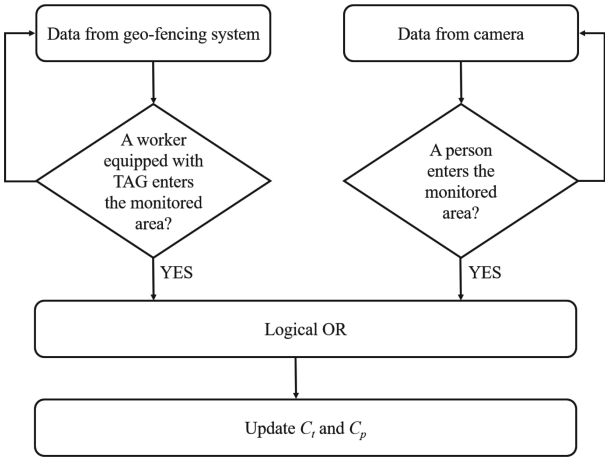

Fig. 4. Flowchart that describes the Data Acquisition and Data Processing.

results obtained confirm those from the offline testing and validation phase (see Sect. 4.2); particularly, it was consistently possible to maintain good visibility and favorable weather conditions, as construction work in open environments is not feasible under adverse conditions.

Furthermore, as an example, Fig. 5 shows a mockup of the web application dashboard, where for each monitored area (AREA 1 in the Figure), the following information is displayed:

- number of authorized persons;
- number of workers without PPEs;
- number of workers with helmet only;
- number of workers with vests only;
- a table listing the alarms, characterized by two columns: timestamp and description.

Furthermore, real-world testing also allowed for evaluating the confidence level of the Deep Learning model in detecting the most common used PPEs (helmet and vest), which was consistently shown to be above 0.8. For instance, an image captured by the camera is presented in Fig. 6.

Finally, real-scenario testing also made it possible to verify the correct use of PPEs. Indeed, there were cases where workers were equipped with helmets but not worn correctly (e.g., carrying the helmet in hand or attached to a belt). In such instances, the platform signals the absence of PPE since the Deep Learning model recognizes the helmet only when it is on the person's head. Similarly, the vest is only recognized if it is fully worn on the worker's body, while it is considered absent if held in hand or worn in an improper position (e.g., around the neck or just on the pants).

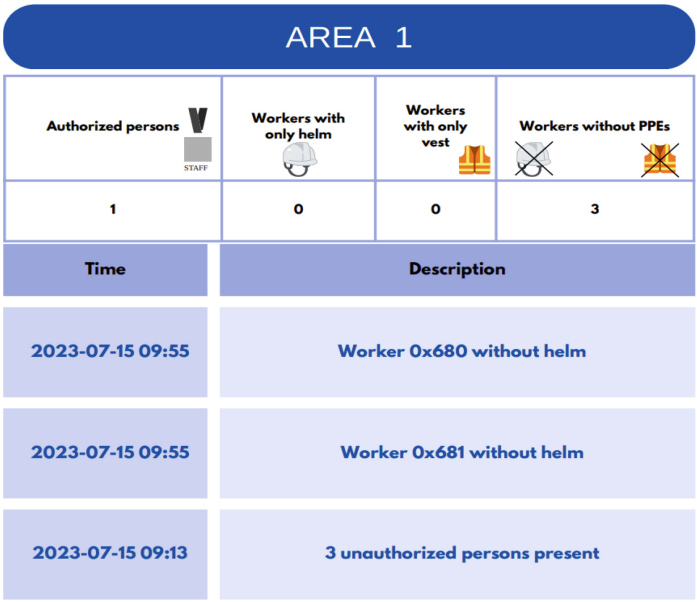

Fig. 5. Example of the WEB Dashboard.

Fig. 6. PPE recognition performed by the network.

5 Conclusions

The goal of this study was to develop an automated hardware and software system for the real-time detection and verification of proper Personal Protective Equipment (PPE) usage by workers on construction sites. This system

autonomously captures images using specialized video surveillance cameras and employs Deep Learning techniques to identify and analyze objects within these images, ensuring adherence to PPE guidelines. The implementation and testing of the innovative monitoring system have demonstrated its efficacy in enhancing safety on construction sites. The system integrates a geo-fencing setup with a sophisticated video surveillance mechanism, accurately detecting and monitoring the presence and movement of workers within the site. Crucially, it identifies whether personnel are correctly equipped with the required PPE.

The employed Deep Learning model was trained on an online available dataset and achieved a mean Average Precision (mAP) greater than 0.85 in recognizing helmets and vests. During the experimental setup, data was acquired on a real construction site. The model was tested offline on this real dataset, showing minimal deviation in performance metrics (e.g., mAP for vests was 0.85 compared to a previous 0.91). Subsequent real-time tests on the construction site evaluated the system's performance, confirming consistency with offline results. These tests included verifying worker detection, PPE recognition, and system integration with the IoT Platform.

In addressing the objectives, the initial data acquisition phase ensured a robust dataset for training and validation. The offline phase allowed for software optimization and performance assessment. Finally, the real-time phase validated the system's applicability in real-world conditions, confirming its potential to reduce accidents and improve safety compliance.

Future work will refine the system's capabilities and explore its applicability in other high-risk environments, aiming to further enhance safety protocols and compliance on construction sites.

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Knowledge-Based Model for Detecting Neurodegenerative Diseases Using Text Complexity Measures

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Abstract. The incidence of neurodegenerative diseases affecting the brain and its cognitive functions, including language and speech, is increasing in society. These diseases impact the manner and quality of speech and can be detected through non-invasive methods. Understanding language involves analyzing internal linguistic features such as text readability and complexity. Language complexity is a significant measure of an individual's linguistic development, representing an independent dimension of utterance (whether written or spoken) and manifesting across all linguistic levels (phonological, morphological, syntactic, and semantic). The aim of this research is to identify linguistic features – measures of text complexity – that may serve as predictors for a knowledge-based model to detect neurodegenerative diseases such as Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), and Parkinson's Disease (PD) in the context of the inflectional Slovak language.

The results indicate that lexical measures of language complexity that are independent of text length are unsuitable for predicting neurodegenerative diseases such as AD/MCI or PD. However, they can be useful in distinguishing between AD/MCI and PD. The rate of action in describing a situational picture is a strong predictor for distinguishing AD/MCI but not PD. The sequence of two verbs is a strong predictor for diagnosing both AD/MCI and PD, but does not distinguish between these diseases. Last but not least, vocabulary range and diversity influence not only the diagnosis of neurodegenerative diseases, but also help differentiate between AD and PD.

Keywords: artificial intelligence · healthcare · neurodegenerative diseases · language complexity

1 Introduction

Advances in language research are largely driven by artificial intelligence (AI) and natural language processing (NLP). The rapid development of AI is revolutionizing language-related research and industries. Understanding a language involves analyzing

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internal linguistic features such as text readability or complexity. Language complexity is a significant measure of an individual's linguistic development, representing an independent dimension of utterance (whether written or spoken) and manifesting across all linguistic levels—phonological, morphological, syntactic, and semantic. Speech is a complex process integral to activating various cognitive functions [1]. A decline in one cognitive function can easily impact others.

Neurologists nowadays no longer see neurodegenerative diseases such as Parkinson's and Alzheimer's as single entities, but rather as a spectrum of multifaceted symptoms with varying progression and treatment responses [2]. Clinically, these diseases rarely present uniform symptoms [3] and the heterogeneity of neurological and psychiatric symptoms often hinders timely diagnosis and treatment [4]. There is increasing interest in using AI techniques to assist in diagnosing Alzheimer's disease, drawing on various data sources such as magnetic resonance imaging (MRI), positron emission tomography (PET), electroencephalography (EEG), magnetoencephalography (MEG), and sensor data [5], but all of them are invasive techniques, for instance, [6] used neuroimaging, genetic markers, and clinical data to train a model (classifier) to differentiate between healthy people and people with dementia and between different types of dementia. Moreover, these techniques are costly and require lengthy medical evaluations, which has increased interest in developing new technological approaches to assist in the clinical diagnosis and assessment of Alzheimer's disease (AD). These approaches utilize a variety of predictors, ranging from sociodemographic, cognitive, imaging, and biomedical to genetic variables [7].

The ability to express oneself and understand others through language is crucial for daily life [8]. Observations of language impairment in neurodegenerative diseases have led to the term Primary Progressive Aphasia [9], which is described by three syndromes - fluent speech with semantic breakdown, non-fluent speech with agrammatism, and impaired repetition with phonologic errors [8].

Linguistic deficits, such as progressive aphasia, have been noted in many neurodegenerative disorders, including Alzheimer's and Parkinson's diseases [10–13]. Language difficulties of the progressive aphasias can be classified into three subtypes: the non-fluent variant (characterized by grammatical difficulties or speech apraxia), the semantic variant (marked by impaired naming and word comprehension), and the logopenic variant (notable for word retrieval problems and difficulties in sentence repetition) [14–16]. Individuals with the non-fluent variant exhibit effortful speech, morpho-syntactic deficits, agrammatism, oversimplified language, and/or speech apraxia, leading to loss of prosody and articulatory errors [12]. Those with the semantic variant suffer from severe anomia and consistent difficulty comprehending single words, due to the degradation of semantic representations [12]. Individuals suffering from the logopenic variant present significant word-finding difficulties, difficulties in sentence repetition, the absence of agrammatism, apraxia of speech, and semantic memory impairment [12].

The research [17] has attempted to redefine diagnostic criteria for Parkinson's and Alzheimer's diseases, shifting from data-based to knowledge-based models with a focus on patient-specific phenotypes [18].

Patients with Mild Cognitive Impairment (MCI) exhibit language impairments similar to early-stage Alzheimer's, including declines in lexical-semantic abilities, word

comprehension, and verbal fluency [19]. Some studies have reported a simplification of syntactic structure [20]. Parkinson's Disease (PD) is often associated with a disruption in motor speech, and language deficits involving morpho-syntactic processing (verb inflection, verb generation, and sentence comprehension). Pragmatic difficulties affect the ability to understand metaphoric meanings or ironic remarks [12].

Several methods or tasks are used to diagnose neurodegenerative diseases, typically categorized into semi-spontaneous and spontaneous speech production tasks. Semi-spontaneous tasks include situational image descriptions (picture description) and storytelling (story narration), which require structured speech. Spontaneous speech tasks include interviews and conversations, allowing more freedom in response (in terms of time and quantity). This study employs semi-spontaneous speech production using a picture description task (PDT), where participants describe a simple scene. This task requires minimal instructions and interventions. PDT is usually used to assess the lexico-semantic level of the speech, syntactic structure variety, and semantic deficits. The advantages of PDT include easy administration, short task duration, straightforward scoring, and easy comparison across subjects and languages [12].

There are studies examining various linguistic predictors to train a model differentiating utterance (speech) of healthy people and people with AD, MCI, or PD (e.g. [21–24]), but none of them has focused on low-resource languages such as Slovak.

The aim of this study is to identify linguistic features – measures of text complexity – that may help predict the diagnoses of Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), and Parkinson's Disease (PD). Linguistic predictors for a knowledge-based model for detecting neurodegenerative diseases by people speaking an inflected language – Slovak – will be determined. The Slovak language, a synthetic language, relies heavily on inflectional morphemes to convey word relationships and meanings in sentences [25]. Also, declination and a relatively free word order depend on the case of the words used in a sentence and their meaning. Syntax and grammatical constructions are not as fixed in Slovak as compared to English, in which syntactic relations are presented by auxiliaries and a more fixed word order, with the word position in syntactic structures indicating the position of sentence elements [26].

While extensive research exists on widely-spoken languages such as English or Spanish, less is known about Slovak, one of the official EU languages. This study provides an insight into the language impairment of people suffering with neurodegenerative diseases and methods to predict these diseases using a knowledge-based model, reflecting the linguistic features of text complexity.

The study is divided as follows: the next section briefly describes linguistic features that can reflect language impairment. The third section is devoted to the research itself, wherein we describe methods and procedure. In the fourth section, the results are presented. The research findings are interpreted in the final section, which contains the conclusions of the study.

2 Linguistic Features Reflecting Text Complexity for Language Impairment

Linguistic features serve as measures to describe and evaluate both the quantitative and qualitative aspects of language production. These features can be categorized, for instance, into phonetic-phonological, morpho-syntactic, lexico-semantic, and discourse-pragmatic levels. In our study, we focus on measures reflecting lexico-semantic aspects of language production (text complexity), as they capture language impairment at word and content levels.

Lexical features include basic vocabulary range (lexicon), lexical diversity, and lexical variation. Vocabulary range refers to the number of words across different part-of-speech categories. Lexical diversity is the ratio of the number of unique tokens to the total number of tokens. Lexical variation encompasses lexical density (the ratio of content words – such as verbs, nouns, adjectives, and adverbs – to the total number of words in discourse) and the distribution of these content words among themselves. Lexical density indicates the richness of discourse in content words which helps us to assess its complexity.

In Slovak, words are classified into ten part-of-speech (POS) categories: nouns, adjectives, pronouns, numbers, verbs, adverbs, prepositions, conjunctions, particles, and interjections. The occurrence of these POS categories can help identify deictic expressions (including personal pronouns and demonstratives), which are typical in the speech of individuals with Alzheimer's Disease or Parkinson's Disease. At the content level, linguistic features can capture lexical richness or density, indicating how informative a discourse is. Measures such as word or token frequencies, type frequencies, verb distance, activity, TTR (Type-Token Ratio), MATTR (Moving-Average Type-Token Ratio), and MAMR (Mean Length of Utterance) can be employed to assess lexical density.

3 Methodology

The most frequently used tasks for discourse evaluation and detection of neurodegenerative disease symptoms are picture description tasks [27]. However, these samples are not easy to obtain in large quantities. Therefore, researchers very often compare the discourse of people with Alzheimer's disease and healthy individuals using a balanced dataset [28–30]. The dataset is mostly balanced based on three demographic characteristics: age, gender, and education.

The data for this study were obtained from the EWA (Early Warning of Alzheimer) project [31]. The data consist of discourse transcriptions describing a particular picture, produced by healthy individuals and those diagnosed with neurodegenerative diseases, who were recruited from across Slovakia. Participants had to meet certain criteria: age 50 and over, no serious psychiatric or neurological disease, no speech disorder, and no serious visual impairment. For our study, we selected a balanced dataset of 420 participants, with 210 healthy individuals and 210 diagnosed with AD and MCI (76) and Parkinson's Disease (PD) (134).

Within the lexico-semantic features at the word and content levels we focused on the following measures of text complexity: the number of individual words in the text

(tokens), the ratio of the number of different words (types), verb distance, activity, average token length, moving average TTR, and moving average of morphological richness.

To calculate these measures, we used QuitaUp, a tool for quantitative stylometric analysis [32]. In the analysis, a token measure is characterized as a sequence of characters separated by spaces, and token frequency corresponds to the length of the text (discourse, in our case a picture description). A type measure represents the absolute frequency of all types in a text, corresponding to the number of different words in the text (discourse). The verb distance (vdist) measure is the arithmetic mean of the number of tokens between two consecutive verbs (ignoring auxiliary verbs). The activity measure expresses the degree of action of a text; it is the ratio of verbs (V) to the sum of verbs (V) and adjectives (ADJ) in a text, i.e., $Q = \frac{\#Verb}{\#(Verbs+Adjectives)}$. The average token length (alt) measure is calculated as the arithmetic mean of the token lengths (number of characters) in the text. The moving average TTR (MATTR) measure is one of the indices of lexical density, independent of text length, and is calculated as follows: $MATTR = \frac{\sum_{i=1}^{N-L} V_i}{L(N-L+1)}$, where N is the number of tokens, L is the window size (in our case, $L = 100$), V_i is the number of types in the window. The last measure applied from QuitaUp is the moving average of morphological richness (MAMR). It is the difference between the MATTR values for non-lemmatized and lemmatized text; it expresses the degree of various word forms usage within discourse and it is independent of text length: $MAMR = MATTR_{wordforms} - MATTR_{lemmas}$.

3.1 Hypothesis

We hypothesize that metrics of language complexity such as frequency of word tokens and types may serve as predictors in diagnosing Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), or Parkinson's Disease (PD).

We hypothesize that language complexity metrics such as verb distance and activity may serve as predictors in diagnosing Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), or Parkinson's Disease (PD).

We hypothesize that language complexity metrics such as average token length, moving average TTR, and moving average morphological richness may serve as predictors in diagnosing Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), or Parkinson's Disease (PD).

3.2 Data Exploration

To identify associations between the examined measures of text complexity (*tokens*, *types*, *vdist*, *activity*, *atl*, *mattr*, and *mamr*) and the corresponding AD+MCI diagnosis (0/1), and/or PD (0/1) non-parametric procedures were used (Tables 1, 2 and 3), due to the binary character of the variables representing the relevant diagnosis, as well as the identified deviations from normality in the case of the examined measures of text complexity (Shapiro-Wilk test: $N = 420$, $W < 0.992$, $p < 0.0222$).

For the variables *tokens* and *types* (Table 1), a statistically significant large degree of negative association ($Gamma < -0.5$) was identified between the relevant measures of complexity and the AD + MCI diagnosis (0/1). Similarly, for the variables *vdist*, *atl*,

Table 1. Gamma coefficients: complexity measures x AD + MCI.

	Valid N	Gamma	Z	p-value
tokens & AD+MCI	286	−0.64***	−10.031	0.0000
types & AD+MCI	286	−0.69***	−10.874	0.0000
vdist & AD+MCI	286	−0.28***	−4.407	0.0000
activity & AD+MCI	286	0.22***	3.505	0.0005
atl & AD+MCI	286	−0.15*	−2.333	0.0196
mattr & AD+MCI	286	−0.19**	−3.060	0.0022
mamr & AD+MCI	286	−0.14*	−2.282	0.0225

Note: *** - $p < 0.001$, ** - $p < 0.01$, * - $p < 0.05$

mattr, and *mamr* (Table 1) a statistically significant small degree of negative association was identified ($Gamma < -0.1$). On the contrary, in the case of the variable *activity* (Table 1), a statistically significant small degree of positive association ($Gamma > 0.1$) was identified between the *activity* and the diagnosis of AD+MCI (0/1).

Table 2. Gamma coefficients: complexity measures x PD.

	Valid N	Gamma	Z	p-value
tokens & PD	344	−0.37***	−6.991	0.0000
types & PD	344	−0.36***	−6.806	0.0000
vdist & PD	344	−0.23***	−4.391	0.0000
activity & PD	344	0.08	1.583	0.1133
atl & PD	344	0.11*	2.078	0.0377
mattr & PD	344	0.10*	1.992	0.0464
mamr & PD	344	−0.11*	−2.039	0.0415

Note: *** - $p < 0.001$, ** - $p < 0.01$, * - $p < 0.05$

In the case of PD diagnosis (0/1), a statistically significant moderate degree of negative association ($Gamma < -0.3$) was identified between the *tokens*, *types*, and the relevant diagnosis (Table 2). Similarly, for the variables *vdist* and *mamr* (Table 2) a statistically significant small degree of negative association was identified ($Gamma < -0.1$). On the contrary, in the case of variables *atl* and *mattr* (Table 2), a statistically significant small degree of positive association ($Gamma > 0.1$) was identified between the measures of complexity and the PD diagnosis (0/1). In the case of the *activity* variable (Table 2), independence was identified, and/or only a trivial degree of positive association was identified ($Gamma < 0.1$).

Among the measures of text complexity (Table 3), a maximum moderate degree of association ($Gamma < 0.5$) was identified, with the exception of the variables *tokens*

Table 3. Gamma coefficients: complexity measures.

	tokens	types	vdist	activity	atl	mattr	mamr
tokens	1.00	0.84***	0.23***	−0.08*	−0.18***	−0.02	0.09**
types	0.84***	1.00	0.21***	−0.10**	−0.10**	0.10**	0.03
vdist	0.23***	0.21***	1.00	−0.43***	−0.03	−0.13***	0.20***
activity	−0.08*	−0.10**	−0.43***	1.00	−0.31***	0.00	−0.17***
atl	−0.18***	−0.10**	−0.03	−0.31***	1.00	0.25***	0.00
mattr	−0.02	0.10**	−0.13***	0.00	0.25***	1.00	−0.26***
mamr	0.09**	0.03	0.20***	−0.17***	0.00	−0.26***	1.00

Note: *** - $p < 0.001$, ** - $p < 0.01$, * - $p < 0.05$

and *types*, where a statistically significant very large degree of positive association was achieved (*Gamma* > 0.7). We can observe (Fig. 1) how the values of the *tokens* and *types* variables change in the same direction together, achieving an almost perfect degree of direct dependence compared to the others, where the remaining pairs of measures of text complexity achieve only a moderate degree of dependence to independence.

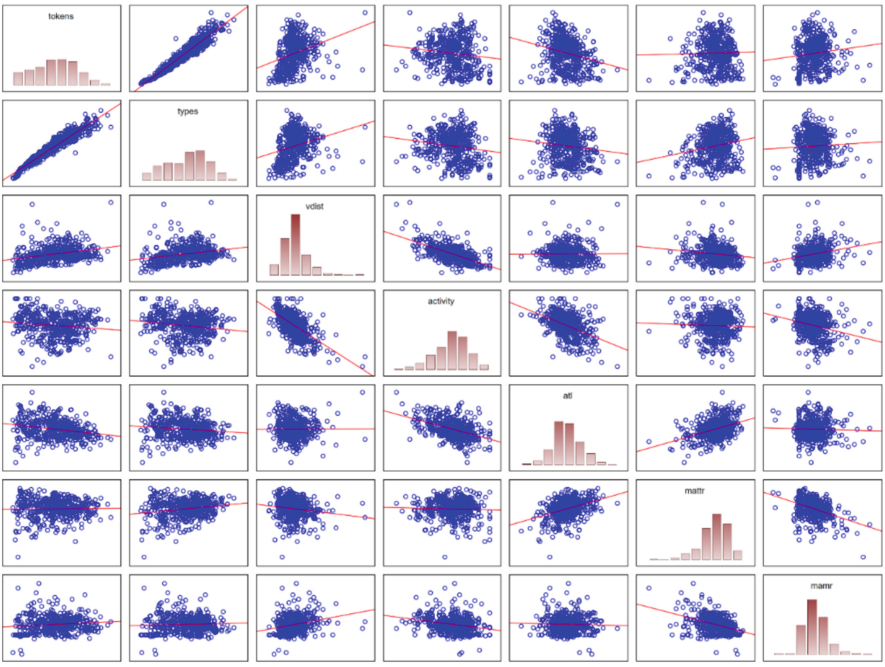

Fig. 1. Matrix plot: complexity measures.

4 Results

Considering the identified deviations from normality as well as differences in the variability of the examined complexity measures (Box test: Box M = 153.876, Chi-sqr. = 149.481, $p < 0.001$) between independent samples (dgn_cat), represented by the relevant diagnosis (AD+MCI/PD /healthy), non-parametric procedures based on rank (Tables 4, 5, 6, 7, 8, 9 and 10) were used.

Table 4. Multiple comparisons of mean ranks for all groups: tokens x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1	2	3
AD+MCI	76	123.15	79.01	****		
PD	134	184.03	102.13		****	
Healthy	210	259.00	129.41			****

Note: *** * - $p > 0.05$

Table 5. Multiple comparisons of mean ranks for all groups: types x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1	2	3
AD+MCI	76	113.88	53.33	****		
PD	134	187.35	69.07		****	
healthy	210	260.24	83.48			****

Note: *** * -$p > 0.05$

Based on the results of the Kruskal-Wallis test by ranks (tokens x dgn_cat: H(2, $N = 420$) = 79.258, $p = 0.0000$, types x dgn_cat: H(2, $N = 420$) = 88.294, $p = 0.0000$) the global null hypotheses at the 0.001 significance level was rejected, claiming that the scores of the complexity measures *tokens* and *types* do not depend on the diagnosis. From multiple comparisons (Tables 4 and 5), statistically significant differences between diagnoses in the scores of the variable *tokens* and *types* were identified. The variables *tokens* and *types* have a good distinguishing ability between healthy and relevant diagnoses as well as between AD+MCI and PD diagnoses themselves.

In the case of the *vdist* complexity measure (vdist x dgn_cat: H(2, $N = 420$) = 19.815, $p = 0.0000$), the global null hypothesis at the 0.001 significance level was rejected, claiming that the *vdist* complexity measure score does not depend on the diagnosis. Based on multiple comparisons (Table 6), a statistically significant difference between healthy and relevant diagnoses (AD+MCI and PD) in the score of the variable *vdist* was identified. On the contrary, there was no statistically significant difference between the diagnoses (AD+MCI, PD) and together, they form one homogeneous group ($p > 0.05$). The *vdist* variable has good distinguishing power between healthy and relevant diagnoses.

Table 6. Multiple comparisons of mean ranks for all groups: vdist x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1	2
AD+MCI	76	176.05	4.88	****	
PD	134	189.33	4.91	****	
healthy	210	236.48	5.41		****

Note: *** * - $p > 0.05$

Table 7. Multiple comparisons of mean ranks for all groups: activity x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1	2
healthy	210	196.56	0.65	****	
PD	134	213.62	0.68	****	****
AD+MCI	76	243.50	0.71		****

Note: *** * - $p > 0.05$

Similarly, also in the case of the *activity* complexity measure (activity x dgn_cat: $H(2, N = 420) = 8.475$, $p = 0.0144$) the global null hypothesis at the 0.05 significance level was rejected, claiming that the *activity* complexity measure score does not depend on the diagnosis. Based on multiple comparisons (Table 7), a statistically significant difference between healthy people and those diagnosed with AD+MCI in the score of the *activity* variable was identified. On the contrary, there was no statistically significant difference between the diagnoses (AD+MCI, PD) as well as between the healthy people and the PD diagnosis ($p > 0.05$). The *activity* variable has a good distinguishing ability between healthy people and those diagnosed by AD+MCI.

Table 8. Multiple Comparisons of mean ranks for all groups: atl x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1	2
AD+MCI	76	178.99	4.42	****	
healthy	210	208.84	4.51	****	****
PD	134	230.97	4.57		****

Note: *** * - $p > 0.05$

Based on the results of the Kruskal-Wallis test by ranks (atl x dgn_cat: $H(2, N = 420) = 8.971$, $p = 0.0113$, mattr x dgn_cat: $H(2, N = 420) = 11.339$, $p = 0.0034$) the global null hypothesis at the 0.05, and/or 0.01 significance level was rejected, claiming that the scores of the *atl* and *mattr* complexity measures do not depend on the diagnosis. From multiple comparisons (Tables 8 and 9), statistically significant differences between the diagnoses in the scores of the *atl* and *mattr* variables were identified. On the contrary, no statistically significant difference was proved between healthy people

Table 9. Multiple Comparisons of mean ranks for all groups: mattr x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1	2
AD+MCI	76	172.66	0.88		****
healthy	210	210.89	0.90	****	****
PD	134	231.35	0.90	****	

Note: *** * - $p > 0.05$

and those diagnosed by AD+MCI, nor between healthy people and those diagnosed by PD ($p > 0.05$). The *atl* and *mattr* variables have good distinguishing power between AD+MCI and PD diagnoses alone.

Table 10. Multiple Comparisons of mean ranks for all groups: mamr x dgn_cat.

dgn_cat	Valid N	Mean Rank	Mean	1
AD+MCI	76	192.38	0.02	****
PD	134	201.01	0.02	****
healthy	210	223.11	0.02	****

Note: *** * - $p > 0.05$

In the case of the *mamr* complexity measure (mamr x dgn_cat: $H(2, N = 420) = 4.780$, $p = 0.0916$), the global null hypothesis was not rejected, i.e. *mamr* complexity measure scores are independent of diagnosis. The *mamr* variable (Table 10) does not have a good distinguishing ability between healthy people and relevant diagnoses, as well as between AD+MCI and PD diagnoses themselves.

5 Conclusions

This study attempted to explore the impact of Alzheimer's disease on vocabulary (lexicon) and to examine how lexical features, particularly measures of lexical complexity, can contribute to creating a knowledge-based model and an automatic classifier for predicting Alzheimer's disease/ Mild cognitive impairment, or Parkinson's disease based on transcribed speech samples or written texts from individuals with AD/MCI or PD and healthy people.

Our results can be summarized by the following key findings:

Lexical measures of language complexity that are independent of text length, such as moving average TTR (MATTR) and moving average of morphological richness (MAMR), are unsuitable for predicting neurodegenerative diseases such as AD/MCI or PD. When creating a classifier, we should not include predictors such as moving average TTR (MATTR) or moving average of morphological richness (MAMR) in the model. These measures, which index lexical richness, did not show significant differences between healthy individuals and those with AD/MCI or PD, even though healthy

individuals exhibited greater word diversity. Notably, MAMR, which represents the use of different word forms typical in such inflectional languages as Slovak, did not differentiate between healthy and diagnosed individuals.

The results indicate that there is no difference in word form usage rate and lexical richness between healthy individuals and people diagnosed with AD/MCI and PD. Variables that capture lexical richness such as MATTR or MAMR do not determine the diagnosis of the disease in the context of Slovak. It is convenient to implement the MATTR measure into the model, which further determines whether it is AD/MCI or PD.

The second remarkable finding is the fact that even the average word length does not influence the determination of AD/MCI or PD diagnoses. However, it can be useful in distinguishing between AD/MCI and PD. This finding suggests that the use of short (one- or two-syllable) versus long words (three or more syllables) is similar in both healthy individuals and those with AD/MCI or PD, but varies between the two diseases.

The third remarkable finding is the fact that the activity measure, which indicates the rate of action in describing a situational picture, is a strong predictor for distinguishing AD/MCI but not PD. It showed the highest scores in individuals with AD/MCI, making it a suitable predictor for these conditions, but it is not effective for predicting PD.

A fourth interesting result is that the sequence of two verbs (verb distance) is a strong predictor for diagnosing AD/MCI and PD, but does not distinguish between them. In contrast, linguistic features that characterize lexical richness can differentiate between AD/MCI and PD.

A final finding is the fact that vocabulary range and diversity influence not only the diagnosis of neurodegenerative diseases, but also help differentiate between AD/MCI and PD.

The results of this research contribute to the literature, particularly because no similar study has focused on Slovak. Additionally, these findings can help in the development of an automatic classifier based on our predictors, enhancing early diagnosis and intervention for neurodegenerative diseases.

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A Web Tool for Representing Algorithmic Flowcharts and Its Support for Pseudocode Learning

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Abstract. Developing computer programming and problem-solving skills are fundamental skills for the future of those who obtain training in the Science, Technology, Engineering and Math (STEM) areas. Two simple and basic ways to develop these skills are through flowcharts and pseudocode.

The aim of this research is to identify the advantages of using these two methodologies for teaching computer programming and problem solving and how each can help the other, as well as carrying out a survey of the tools currently available to support teaching and finally build a simple, intuitive and easy-to-use web tool that allows you to easily convert between flowcharts and pseudocode.

The web tool developed meets the requirements of being simplicity, intuitively and easy-to-use and allows conversion between flowcharts and pseudocode, becoming an important aid to students who can now use it to study anytime and anywhere.

Keywords: Computer programming · Flowcharts · Pseudocode · Problem Solving

1 Introduction

In the domain of Sciences, Technology, Engineering and Math (STEM) education, mastering the fundamentals of programming logic is a critical step for students. Two essential tools that aid in understanding and designing algorithms are flowcharts and pseudocode [1–3]. Flowcharts provide a visual representation of the logical flow of a program, using standardized symbols to denote different types of actions or decisions [2]. Pseudocode, on the other hand, offers a textual representation that closely resembles the structure of actual programming languages but is simplified to focus on the logic rather than syntax [3].

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Despite the clear benefits of using both flowcharts and pseudocode in teaching programming concepts, students often struggle to seamlessly transition between these two forms of representation [4]. This transition is crucial for developing a comprehensive understanding of how abstract concepts translate into executable code [5, 6]. Currently, educators face challenges in providing tools that effectively bridge this gap, often resorting to manual translation, which can be time-consuming and error prone. By automating the conversion process, it would help to eliminate common errors, save time, and enable students to focus more on learning the core principles of programming [7].

One of the primary difficulties for beginners is grasping the logical structure of programs. Studies show that many students find it challenging to comprehend abstract concepts such as loops, conditionals, and recursion [8]. Beginners frequently conflate syntax (the structure of code) with semantics (the meaning behind the code) [9]. This confusion can lead to syntactically correct but logically incorrect programs. Developing the ability to think algorithmically is essential for solving programming problems. This skill involves breaking down problems into step-by-step procedures, which many novices find daunting [10]. The initial learning phase often overwhelms students with information. The simultaneous need to understand programming logic, syntax, and problem-solving strategies can lead to cognitive overload [11].

It is aim of this research to identify the advantages of using these two methodologies for teaching computer programming and problem solving and how each can help the other, as well as carrying out a survey of the tools currently available to support teaching and finally build a simple, intuitive and easy-to-use web tool that allows you to easily convert between flowcharts and pseudocode.

This document is organized in six sections, being the first the introduction, followed by the pseudocode learning, flowchart learning, flowchart supporting the pseudocode, existing web tools for learning flowcharts and pseudocode, the developed web tool and remarked with the discussion.

2 Learning Computer Programming with Pseudocode

Pseudocode provides a bridge between human thinking and programming languages by allowing students to focus on the logic without worrying about specific syntax. It uses a structured yet flexible notation that can easily be translated into any programming language [3].

Pseudocode is a high-level description of an algorithm or computer program that uses the structural conventions of programming languages but omits detailed syntax. It is widely used as a pedagogical tool in computer science education to bridge the gap between the conceptual understanding of algorithms and the implementation of code in a specific programming language [3].

One of the primary advantages of pseudocode is that it allows students to concentrate on the logic and structure of algorithms without being hindered by the syntax rules of a particular programming language. This focus on logical thinking helps students develop a clear understanding of the problem-solving process [12]. Pseudocode is not tied to any specific programming language, making it a versatile tool for teaching programming concepts. This language independence enables students to transfer their skills across

different programming languages more easily [3]. The simplified and informal nature of pseudocode makes it easier for students to grasp complex concepts. By reducing the cognitive load associated with learning intricate syntax, pseudocode facilitates a smoother introduction to programming [8]. Writing pseudocode encourages students to think in a structured and systematic way. This structured thinking is essential for developing algorithms and for understanding the flow of control in programs [13]. Pseudocode allows students to outline their problem-solving approach in a step-by-step manner. This stepwise refinement is critical for breaking down complex problems into manageable parts and for debugging algorithms [9].

Studies [14] have shown that the use of pseudocode can improve students' comprehension of programming concepts. By abstracting away the syntax, students can better focus on understanding the underlying logic. It can make learning programming more engaging for students who might be intimidated by the complexity of syntax. It allows them to express their ideas more freely and experiment with different solutions [15]. It serves as an intermediate step between problem-solving and code implementation. It provides a clear roadmap that students can follow when translating their ideas into actual code, thereby reducing errors and improving code quality [3].

Pseudocode is commonly used in algorithm design courses to help students develop and test algorithms before implementing them in a programming language. This approach ensures that students understand the algorithm's logic before dealing with syntax [16]. In introductory programming courses, students are often required to write pseudocode as part of their assignments. This practice helps them plan their programs more effectively and lays a solid foundation for writing code [3]. Pseudocode is frequently used in examinations to assess students' understanding of algorithms and problem-solving strategies. It allows instructors to evaluate students' logical thinking and algorithmic skills without the confounding factor of syntax errors [17].

One of the challenges with using pseudocode is the lack of a standardized syntax. Different textbooks and instructors may use different conventions, which can confuse students. Establishing a consistent set of guidelines can help mitigate this issue [18]. While pseudocode is excellent for planning and understanding, students may struggle with transitioning from pseudocode to actual code. Instructors need to provide clear examples and support to help students make this transition smoothly [19]. Providing effective feedback on pseudocode can be challenging because it is less formalized than actual code. Instructors must focus on the logical correctness and clarity of pseudocode rather than stylistic issues [20].

The use of pseudocode in educational settings can significantly enhance students' understanding and engagement with computer programming and problem-solving learning.

3 Learning Computer Programming with Flowcharts

Flowcharts serve as a powerful visual tool to represent the flow of control within a program. They help in visualizing the sequence of operations and decision-making paths, making abstract concepts more concrete. They are diagrammatic representations of algorithms or processes, often used in programming education to visually depict the flow of control in a program. They employ standardized symbols to represent different types of actions or steps, making them an effective tool for illustrating the logical sequence of operations in a program [2].

Flowcharts provide a clear and visual way to represent the flow of a program, helping students to easily understand and follow the logic. This visual representation can simplify complex algorithms and make the flow of control more comprehensible [21]. For beginners, abstract concepts such as loops, conditionals, and recursion can be difficult to grasp. Flowcharts break down these concepts into more digestible parts by visually mapping out the steps involved in the process [22]. Flowcharts help in identifying logical errors and inefficiencies in an algorithm. By visualizing the entire process, students can more easily spot where things might go wrong or where improvements can be made [23]. Creating flowcharts encourages a structured approach to problem-solving. Students learn to decompose problems into smaller, manageable steps, which can improve their analytical and problem-solving skills [24]. Flowcharts serve as a universal language for programmers. They facilitate better communication of ideas and algorithms among students and between students and instructors [25].

Flowcharts reduce cognitive load by allowing students to visualize the steps of an algorithm. This visual aid can help in understanding and retaining complex programming concepts [11]. They act as a scaffold that supports students as they learn to program. By providing a clear framework for the logic of a program, flowcharts help students gradually move from conceptual understanding to actual coding [26]. Using flowcharts, students can incrementally build their understanding of programming constructs. They can start with simple flowcharts for basic algorithms and gradually progress to more complex ones, which mirrors the progressive nature of learning programming [27].

Flowcharts are extensively used in algorithm design courses to help students plan and visualize the steps of an algorithm before coding. This practice ensures that students thoroughly understand the algorithm's logic [16]. In introductory programming courses, students are often required to create flowcharts as part of their assignments. This exercise helps them plan their programs more effectively and lays a solid foundation for writing code [28]. Flowcharts are frequently used in exams to assess students' understanding of algorithms and their ability to plan and visualize program logic. This method allows instructors to evaluate students' problem-solving skills without the complication of syntax errors [29, 30].

One potential drawback of using flowcharts is that they can sometimes oversimplify complex algorithms, leading students to miss important nuances. Instructors need to balance the use of flowcharts with other teaching methods to ensure a deep understanding [21]. Students may struggle with transitioning from flowcharts to actual code. While flowcharts are excellent for planning, they lack the detail required for coding, necessitating additional instruction on how to translate flowchart steps into code [22]. Creating detailed flowcharts can be time-consuming. Lecturers need to manage class time effectively to ensure that students do not spend too much time on flowcharts at the expense of coding practice [23].

The use of flowcharts in an educational context can significantly improve students' understanding and engagement with learning computer programming and problem solving.

4 Flowchart Tools to Aid Pseudocode Learning

Many flowchart tools are interactive, allowing students to create and modify flowcharts dynamically. This interactivity engages students in active learning, which has been shown to improve understanding and retention of material [31]. By visualizing the logic of an algorithm, flowchart tools make it easier for students to translate their flowcharts into pseudocode. The step-by-step nature of flowcharts corresponds closely with the structure of pseudocode, providing a clear path for conversion [21]. Flowchart tools can help students identify and correct logical errors before they translate their algorithms into pseudocode. This preemptive error detection reduces the likelihood of syntax-related mistakes and enhances the overall quality of their pseudocode [23].

Flowchart tools cater to various learning styles, particularly visual learners who benefit from seeing the flow of control in a graphical format. This inclusivity ensures that a broader range of students can effectively learn and understand pseudocode [31].

While flowchart tools are beneficial, there is a risk of students becoming overly reliant on visual aids. This reliance can hinder their ability to understand and write pseudocode or actual code without the support of flowcharts [21]. Students may find it challenging to transition from flowcharts to pseudocode, particularly if they do not understand the underlying logic well enough. Instructors need to provide clear guidance and examples to help students make this transition smoothly [22]. Some flowchart tools may have technical limitations or lack features necessary for advanced learning. Choosing the right tool that balances ease of use with functionality is crucial for maximizing the educational benefits [23].

Despite some challenges, the use of flowchart tools in educational settings can enhance comprehension, support diverse learning styles, and facilitate the transition from algorithmic design to pseudocode.

5 Existing Web Applications to Support Flowchart Development

Web-based tools are accessible from any device with an internet connection, making them convenient for students to use both in and out of the classroom [32]. These tools often include interactive elements that engage students actively, such as drag-and-drop interfaces for creating flowcharts and real-time conversion to pseudocode. Interactivity has been shown to improve learning outcomes by maintaining student engagement [33]. Automated tools provide immediate feedback, which is crucial for learning. Students can quickly see the results of their work and understand their mistakes, fostering a better learning environment [34]. By automating the conversion process, web-based tools help reduce common errors that occur when manually translating between flowcharts and pseudocode. This ensures that students focus more on understanding the logic rather than getting bogged down by translation errors [35]. Web-based tools can be easily scaled to accommodate large numbers of students without the need for additional physical resources. This makes them cost-effective for educational institutions [36].

Examples of tools that currently exist to aid in the learning of programming concepts through flowcharts and pseudocode are:

- Flowgorithm, a popular tool that allows users to create flowcharts and convert them into pseudocode and vice versa. However, it requires installation and does not fully leverage the benefits of web-based accessibility [37].
- Lucidchart, a versatile online diagramming tool that supports flowchart creation. While powerful, it is not specifically tailored for educational purposes and lacks features focused on the seamless transition between flowcharts and pseudocode [38].
- Raptor, a tool designed to help students learn programming through flowcharts. It offers some pseudocode conversion capabilities but is limited by its desktop-based application model [39].
- Portugol, the desktop application offers two main methods for editing algorithms: creating flowcharts and editing pseudocode. It offers the possibility of pseudocode editing, which is similar with traditional programming [40].

Since none of the solutions found available on the market satisfies the condition of web application for automatic conversion from flowchart to pseudocode in learning basic computer programming skills and problem solving, this research group decided to move forward with the construction of a solution to respond to this gap.

6 The Proposed Web-Based Tool to Support Early Computer Programmers

It was decided that the application to be developed had to be executed in a browser and would have to be executed on the client side. The interface should be simple and intuitive.

In the case of flowcharts, the common elements of flowcharts (including control and repetition structures) should appear on the left side and users should drag them by drag n' drop building the solution to a problem, allowing the corresponding pseudocode to be automatically generated.

As for the pseudocode, the interface must present a text editor where it will be possible to write the pseudocode that must be validated and automatically generate the corresponding flowchart.

In terms of backend, several modules were developed:

- server.js: which configures and starts the JavaScript express server.
- errorHandler.js: handles application errors.
- conversion.js: defines the data model for conversions.
- conversionController.js: which generates the conversion logic from pseudocode to flowcharts and vice versa.
- pseudocodeParser.js: analyzes the pseudocode and transforms it into a structure used by converter.js
- flowchart.js: creates and manipulates flowcharts, has methods to add elements, add links between elements, and convert the diagram into a format compatible with the GoJS library.

For the frontend, the JavaScript React framework was used, to which the following components were added:

- HomePage.js: Application home page.
- PseudocodePage.js: converting pseudocode into flowchart.
- FlowchartPage.js: converting flowcharts into pseudocode.

6.1 How Pseudocode to Flowchart Conversion Works

The parse method receives the pseudocode as input and splits it into individual lines. Each line is then mapped to an object that represents the type of instruction (start, end, condition, cycle, input, output, or operation). The result is a list of objects, where each object contains the instruction type and associated content. The convertToFlowchart method uses the PseudocodeParser to parse the pseudocode and creates a flowchart based on the objects returned by the parser.

6.2 How the Flowchart to Pseudocode Conversion Works

Diagram elements (Start, End, Operation, Condition, Loop, Input, and Output) are defined as classes that inherit from FlowchartElement. The toGoJsDiagram method converts the internal flowchart into a GoJS diagram, which can be rendered visually. The convertToPseudocode method parses the flowchart in JSON format and reconstructs the corresponding pseudocode using a breadth-first search (BFS) to traverse the graph of diagram elements.

The Fig. 1 presents the class diagram of the developed classes for the solution.

Examples of execution of the developed web application for conversion between flowchart and pseudocode are presented at Fig. 2 (flowchart to pseudocode) and Fig. 3 (pseudocode to flowchart).

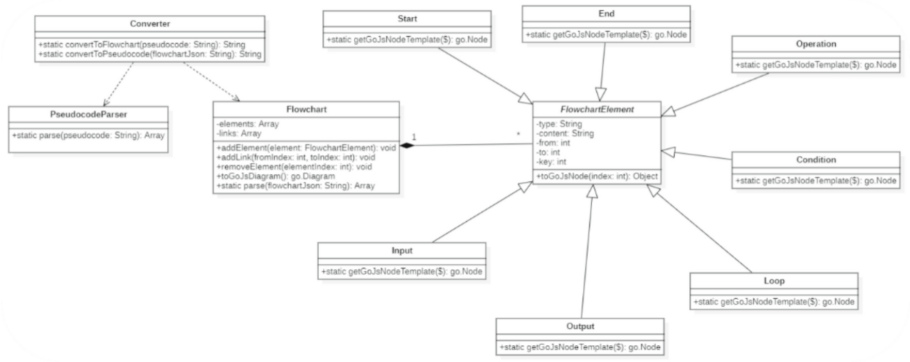

Fig. 1. Class diagram for the conversion between flowchart and pseudocode.

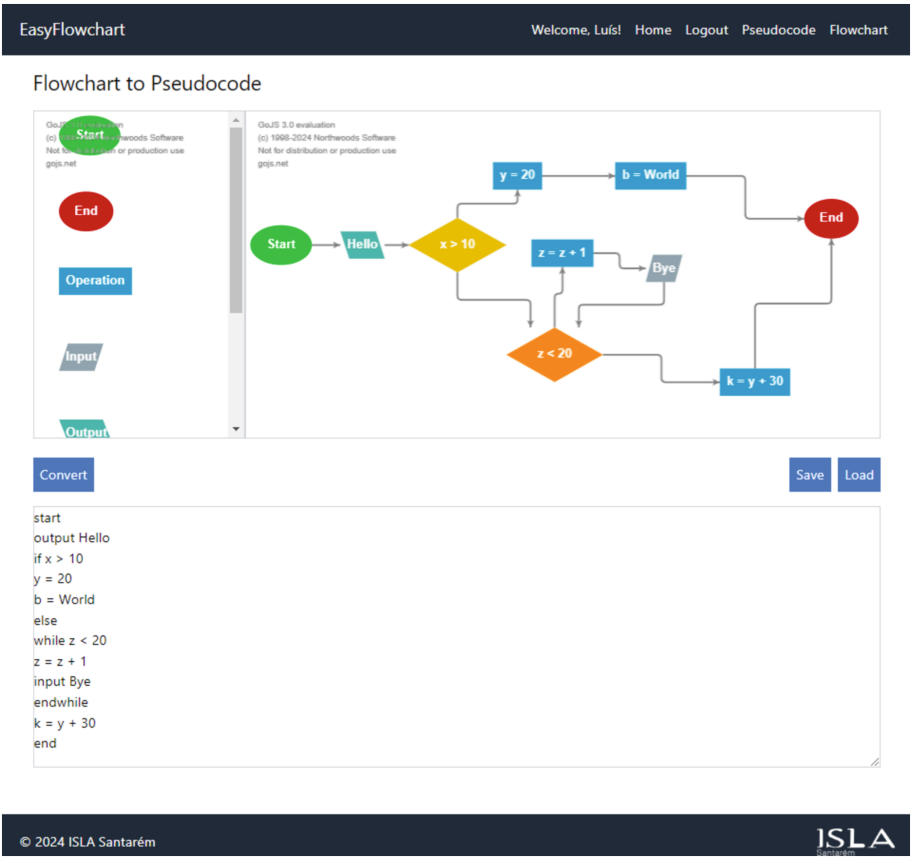

Fig. 2. Example of the conversion from flowchart to pseudocode using the developed application.

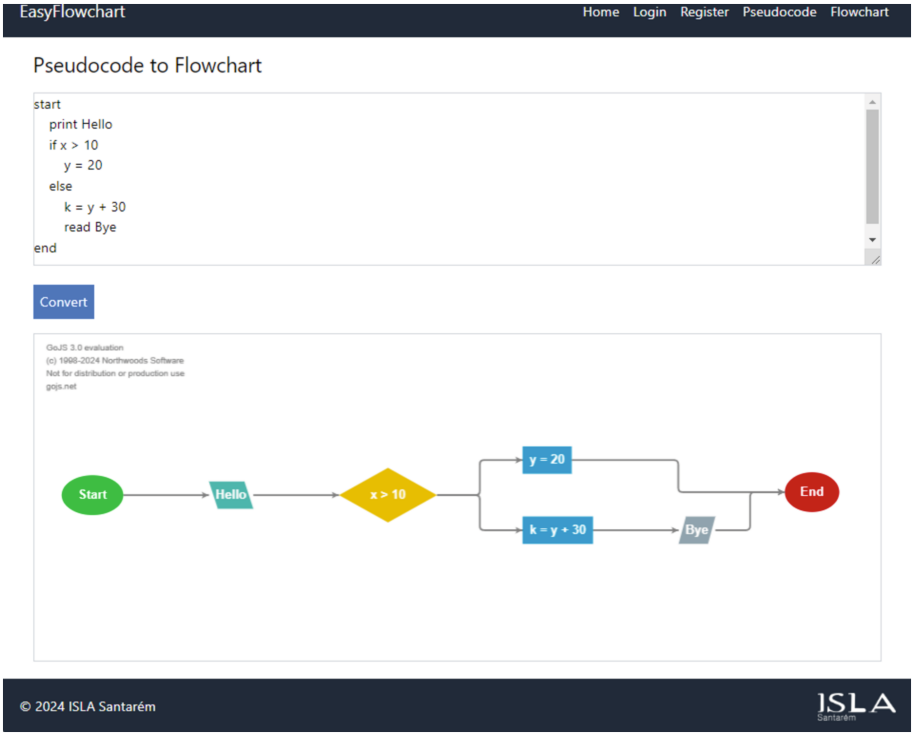

Fig. 3. Example of the conversion from pseudocode to flowchart using the developed application.

7 Discussion

Web-based tools offer several benefits that can enhance the learning experience for programming beginners. They are accessible from any device with an internet connection, making them convenient for students to use both in and out of the classroom. These tools often include interactive elements that engage students actively, such as drag-and-drop interfaces for creating flowcharts and real-time conversion to pseudocode. Interactivity has been shown to improve learning outcomes by maintaining student engagement. Automated tools provide immediate feedback, which is crucial for learning. Students can quickly see the results of their work and understand their mistakes, fostering a better learning environment.

By automating the conversion process, web-based tools help reduce common errors that occur when manually translating between flowcharts and pseudocode. This ensures that students focus more on understanding the logic rather than getting bogged down by translation errors.

Web-based tools can be easily scaled to accommodate large numbers of students without the need for additional physical resources. This makes them cost-effective for educational institutions.

The developed application accomplished all the previously mentioned advantages and can be a useful tool to be used either in the classroom and at any other place, helping them to study and allowing them to study it anytime and anywhere.

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Natural Language Processing Techniques to Identify Work Profiles from Online Job Postings

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Abstract. The present study generates a new methodology which allows us to study the job market in order to identify work profiles based on job openings published online. The methodology includes 5 stages: Web scraping, Data pre-processing, Document filtering (job offers), Topic Modeling, and the Concept Grouping Stage and profile characterization. As a case study, we consider the Psychology profession, for which a corpus of 6,407 job listings was generated. In this case, document filtering was done based on Word2Vec and BERT, with the latter emerging as the better alternative. The corpus was thus reduced to 4,314. For the case study, we also constructed a graphic schema in order to visualize the job offers' location and the graduation profiles with regards to the work profiles identified. The results from the Topic Modeling stage and the graphic projection are presented on dashboards, allowing for user interaction. The methodology developed has potential to help Higher Education Institutions redesign their curricula and review their graduation profiles, both fundamental aspects needed in their Accreditation processes, their continuous improvement and quality assurance processes

Keywords: Natural language processing · Machine learning · Data intelligence · Working market · Work profiles

1 Introduction

The Web is a vast source of information, with abundant data appearing in diverse formats: numbers, images, videos, and text. In particular, social networks can present anything including entire stories, discourses, opinions, sales, and job openings; all in text format, which can be analyzed to find latent information from different dimensions in order to support decision-making. Our study considered the data available from websites which systematically publish job openings, in order to gather requirements for professionals in the Chilean labor market.

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This data source is considered highly useful in order to characterize abilities, skills, and/or knowledge demanded for job market openings and which should be included in the graduation profiles for professionals graduating from Higher Education Institutions. These sites see daily job postings, and several of them specifically describe abilities, skills, and knowledge which companies and institutions seek in their new employees.

To understand the issues considered in this study, let us discuss the following contextual background. First, Universities need updated information on labor market demands, for consideration when redesigning and updating their curricula and the graduation profiles for their graduates. One of the most commonly used mechanisms is to carry out surveys or interviews with employers and graduates. However, these actors' participation level is often low and rather costly.

Second, Particulary in Chile, Law #21091 on Higher Education, within Title IV, article 15 of its text, establishes that institutional accreditation will be mandatory for autonomous Higher Education Institutions. The quality standards and criteria for institutional accreditation and for undergraduate and postgraduate majors and programs are the responsibility of the National Quality Assurance System. In particular, 12 evaluation criteria organized in 3 dimensions have been defined for Professional Majors' accreditation. Within the Major Intentions and Purposes dimension, there is a criterion referring to the Graduation Profile (Criterion #3) which evaluates the existence, systematic application, and results of mechanisms which allow the major to have a pertinent graduation profile which is up-to-date, validated, disseminated, and known within the academic community. In particular, it is expected that majors have systematic mechanisms and policies aimed at knowing current requirements within their profession or discipline, providing feedback about their actions within the graduation profile. There is also a stated need for a periodic review of the graduation profile, with a minimum timeframe of the study plan duration.

Therefore, by developing this new methodology based upon natural language processing (NLP), we hope to offer significant support to universities in their graduation profile review and redesign processes, via analyzing job openings, processing the resulting data, and defining the relevant topics required in the market for various majors.

The present paper is structured as follows: first, there is a bibliographical review about analysis proposals for large volumes of data associated with job offers, topic modeling, and NLP language models. Next, we present the proposed methodology with a detailed description of its 5 stages. Afterwards, in the Results and Discussion section, we indicate the results by using the Psychology major as a case study. The document ends with the Conclusions section.

2 Literature Review

Labor market intelligence has been established as a set of tools which can effectively visualize existing job openings for various interested parties, including both public and private sector entities. Due to its relevance for the society,

research in this area is rapidly expanding. We consider some examples of recent developments that show progress directions related to this research area.

Bojanowski et al. [4] presented in 2017 a tool which makes it possible to automatically process job vacancies found in millions of websites and classify them in a standard taxonomy. Similarly, Colace et al. [6] implemented in 2019 a methodology based on graph models and NLP to classify job openings.

In 2020 Leis [12] used NLP techniques on a corpus containing summaries of publications, position announcements, and course descriptions to model topics and research knowledge, abilities, and skills corresponding to the Modeling and Simulation areas (as a case study). This information was incorporated into a system supporting strategic planning and efficient resource management in a university.

The process of how to achieve the best approach towards the labor market is expanded upon by Muhlbauer et al. [14] in 2022 using automatic learning algorithms and models about administrative data from job biographies. In the same year Tavakoli et al. [21] presented an intelligent recommendation system to match skills required in the job market with the growing supply of educational programs in engineering. The usefulness of the system was tested with job openings related to Data Science.

Convolutional graph techniques were used by Surgiarto [20] also in 2022 to study the complex interaction network between job openings and applicants. Projecting both job offers and applicants within a common space made it possible to automatically approach various relevant problems including job recommendation or identifying similar positions.

The difference between skills required in the job market and those actually acquired within the corresponding college majors was studied by Wang [22] in 2022 through a case study of journalism in China. Information on 720 job openings and 120 university journalism majors was analyzed and systematized by experts, who found important differences in skills associated with data analysis, that were in demand within the job market for journalists, but saw little incorporation within journalism majors' curricula.

A similar gap was also identified in 2022 by Spada et al. [19] between the skills required in the job market and those acquired within higher education for the case of the marketing sector in Italy. Data mining was used to develop an automatic job skill extractor based upon Italian texts. This instrument was used to extract the skills found within both university exams and job openings, indicating the aforementioned gap.

Underlying the use of natural language processing techniques to approach data processing and gathering systems in the job market, we can find the language models or vectorization models. Our study uses two language models, which we will briefly describe.

Text vectorization methods are the first step, and the basis for any application associated with NLP. The most simple and independent language models are based on words' frequency and counts within documents and the general corpus. These methods include BoW (Bag of Words), TF-IDF (term frequency-inverse

document frequency), BM25, and many others (as seen in, e.g., [10]). Counting-based methods usually generate representation vectors which are dispersed, yet high dimensional, which makes subsequent work difficult.

The Word2Vec system was presented in 2013 by Mikolov et al. [15]. It trains simple neural networks in order to generate a smaller dense vectorization which can better capture semantic relations. Other methodologies have been developed based upon similar ideas which refine Word2Vec results, including GloVe [17], Doc2Vec [11], or FastText [3]

The BERT model (Bidirectional Encoder Representations from Transformers) presented in 2019 by Devlin et al. [8] encodes words according to their position within the text, making it possible to capture multiple meanings. The success of BERT is based on its use of Transformer architecture and the large amount of data used in its training. Our study will use the Word2Vec and BERT vectorization models.

One common tool to obtain new knowledge from a text corpus is topic modeling. This tool is systematically used in the aforementioned literature, and will also be applied herein. To this end, we present a bibliographical review related with algorithms for topic modeling.

Topic models were classified by Abdelrazek et al. [1] in 2023 as algebraic, diffuse, probabilistic, and neural. The algebraic models break down the document-term matrix and then find a low-range approximation, based on, for instance, latent semantic analysis [7] or decomposition into singular values [10]. The diffuse models extract topics from the documents, assigning the words to these topics considering a degree of uncertainty, unlike the Boolean logic of "1 or 0". Probabilistic models map the relation between different random variables from the model via a graph, generally a directed acyclic graph (DAG), meaning that they are also called Bayesian models. One of the most popular models in this category is the Latent Dirichlet Assignation (LDiA) [2]. Finally, neural models use incrustations like Word2Vec [15]. One case is the LDA2VEC model [16], which discovers themes by combining the Word2Vec model with LDiA. Other models of this type use Variational Autoencoders (VAE) [9], formulating the inference problem as an optimization problem [1]. For topic analysis in this study, we will use the LDiA algorithm.

3 Methodology

This section lists the 5 stages included in our methodological proposal:

1. **Web Scraping stage**, for automatic data gathering.
2. **Data pre-processing stage**, to group the gathered data, clean them, and pre-process the text.
3. **Document filtering stage** (job offers), to rule out job openings gathered for a particular major, but which did not belong to it.
4. **Topic Model Stage**, to obtain the most relevant concepts from a set of job openings, associated with, for instance $K = 3$ topics.

5. **Concept grouping and profile characterization stage**, where job profiles were conceptualized, given the relevant concepts identified by the topic model.

Our case study will be the Psychology major, where we will apply each methodological step and implement it using Python 3.10. The main text libraries used were: BeautifulSoup 4.12, Selenium 4.19, nltk 3.7, Gensim 4.1, Scikit-learn 1.3, TensorFlow 2.10, Keras 2.10, pyldavis 3.4 and Pandas 2.1.

3.1 Phase 1: Web Scraping

We used web scraping techniques to generate two data sets: One data set associated with job openings, and another data set associated with undergraduate academic programs or majors in existence at the State Universities of Chile. Both data sets were obtained from publicly accessible websites.

Data Associated with Job Openings. To gather job opening-associated data, a web scraping program was implemented. The entry parameter was the name of a particular academic major (within those offered at State Universities in Chile). The program automatically accessed websites publishing job offers, extracting and storing data associated with the job openings found with the requested search. The information from Table 1 was stored for each job listing found.

Table 1. Data storage fields for job offers.

Field	Description
Concept	name of the major where the job search was done
Category	category where the job opening belongs, as given by the publisher
Title	Title under which the job offer was published
Body	Job offer description
Date	Job opening publication date
Location	Job offer location
Workday	Job opening workday type
Inclusion	Boolean variable associated to whether the offer is inclusive or not
Salary	Salary offered for the job
Publisher	Entity publishing the job opening
Tags	Tags assigned by the publisher of the job offer
URL	URL where the job opening was published

The present study gathered data from the following 6 public websites: *chiletrabajos.cl*, *opcionempleo.cl*, *computrabajo.com*, *laborum.cl*, *indeed.com*, and *trabajando.cl*. These sites are the most commonly used for job searches in Chile.

Data Associated with Majors. To gather data associated with the majors incorporated in the academic offerings at 18 State Universities in Chile, a web scraping program was implemented to access the universities' admissions websites, which publish information on each major offered at the university. The program automatically extracts and stores the data fields shown in Table 2.

Table 2. Fields stored for undergraduate majors.

Field	Description
Concept	Major to which the record belongs
University	University offering the major
Faculty	University faculty to which the major belongs
Code	DEMRE code for the major, published on the website
Campus	University campus where the major is offered
Semesters	How many semesters the major lasts
Accreditation	Major accreditation status
Graduate profile	Profile for graduates, as given by universities
Labor field	Professional field where graduates can work, given by the university
Spaces	Annual or semesterly vacancies available in the major
URL	URL of the admissions website for the major

3.2 Phase 2: Data Pre-processing

This stage involves pre-processing the text gathered via the data scraping process. To begin, two text corpora are created. The first (**Openings Corpus**) is the set of job opening descriptions, composed of the *Body* field presented in Table 1. The second corpus (**Majors Corpus**) is the set of graduation profile descriptions (the *Graduate Profile* field in Table 2) joined with the description of the labor field (*Labor Field* column in Table 2).

The following pre-processing techniques were applied to both text corpora:

1. Eliminate *html* characters or those used to encode the text online. We also discarded punctuation symbols, exclamation and question marks, numerical characters, and tittles.
2. Suppressing stopwords.
3. Standardization of word writing (tokens) putting characters into lowercase.

3.3 Phase 3: Document Filtering

This stage involves discarding job openings which were gathered by the web scraping program for a particular major, but which did not actually correspond to it.

The appearance of non-pertinent job openings arises because the web scraping program uses the name of the major to seek out job offers on websites. However, some job listings mention this name in a more bounded sense, and job offers wind up being selected which are not aimed at the major in question.

One good example of this is with the Psychology major, where around 30% of the job listings gathered did not actually correspond to this major. In this case, we observed that openings were gathered where the concept or keyword *Psychology* was included, for instance, to mention a service offered to people who were hired, but the opening was for another type of professional.

To approach this problem, we designed an intermediate step which would automatically discard non-pertinent job openings. This intermediate step was based on two trained language models: a simple Word2Vec model, and a BERT large language model. The models were used to vectorize the documents, followed by constructing a similarity metric between documents. This metric helped us compare each job listing gathered for a particular major with the graduation profiles for this major included in the **Majors Corpus**, thereby quantifying the pertinence of the job opening. The two steps are detailed hereinafter.

Document Vectorization. The Word2Vec and BERT models were trained by joining the **Openings Corpus** and the **Majors Corpus**, for vector representations of the tokens which comprised each document in both corpora.

To train Word2Vec, we used the Skip-gram focus with a window size of 3 and a vector representation of the tokens via 100 components. Defined this way, this small language model has 4.6 million parameters.

In the case of BERT, we used the Base-Multilanguage model pre-trained on the Keras library [5], which has a total of 177 million parameters. To adjust it to our corpus, it was re-trained for 15 epochs, minimizing the Categorical Cross Entropy function. This model was used to obtain a vector representation for the tokens from dimension 768.

Once both models were trained, we obtained a way to represent each token for a document via a vector with 100 characteristics, in the case of Word2Vec, and 768 characteristics in the case of BERT. These characteristics contain the semantic data for each token from the joined corpus. In the case of Word2Vec, each token has a single vector representation, regardless of the context where the token appears in the documents. By contrast, in the case of BERT, a vector representation was obtained for each appearance of the token considering the particular context for the token within the document.

Finally, to vectorize a document from the corpus, in both models we concatenated the vectors which represented the tokens (words) which compose each document from the corpus, thereby generating a matrix with dimensions of $100 \times N$ for Word2Vec and $768 \times N$, for BERT, where N is the amount of words which make up the document. This was done for both the documents in the **Offers Corpus** and those in the **Majors Corpus**. A detailed description of the vectorization methods in general can be found, for instance in [10].

Similarity Between Documents. For each document in both corpora considered herein, we first calculated the centroid for the vectors from documents obtained from the document vectorization step, using the average of the rows in each matrix with dimensions of $100 \times N$ (for Word2Vec) or $768 \times N$ (for BERT). With this procedure, for each document d_O in the **Offers Corpus** and each document d_M in the **Majors Corpus**, a single vector was generated with 100 or 768 components describing the document, as the semantic average of the word vectors (tokens) comprising said document. Next, for each major from State Universities, we filtered the job listings which were gathered (belonging to the **Offers Corpus**) and filtered the **Majors Corpus**, using the name of the major, which resulted in two filtered corpora with only the data from that major. The following procedure was then done:

1. For each document d_O from the filtered Offer Corpus, calculate the similar cosine between the vector for document vd_O which represents it and all the vectors vd_M which represent the documents from the filtered Major Corpus.
2. Average the values for the cosine calculated in the prior step between vd_O and all the vectors from documents vd_M.

The two aforementioned steps constructed a value quantifying the semantic similarity between each job opening and the graduation profiles given by Universities. This similarity has values between -1 and 1. Values close to 1 indicate high similarity. Values around 0 show low or null similarity, and values near -1 indicate that two documents are about opposite topics, in a semantic sense.

Filtering or Discarding Job Offers. Finally, given the similarity metric (cosine), we discarded all job listings for which the similarity average was below a certain threshold.

Empirically, by analyzing various cases of particular majors, we observed that with Word2Vec vectorization the value of the cosine similarity ranged between 0.5 and 0.99. Next, to rule out around 30% of job openings (see Phase 3:Document filtering), a value equal to 0.91 was determined, i.e., all job offers below this value were discarded.

Similarly, we observed that the cosine similarity with BERT vectorization ranged between 0.35 and 0.98. In this case, job openings with similarity below 0.70 were discarded.

3.4 Phase 4: Topic Modeling

In this stage, a topic model was used to reduce the job offer corpus for a particular major to the most relevant concepts which characterize a number K of topics or themes. The hypothesis for this study is that of the K topics extracted, at least one of them corresponds to the characterization of a job profile associated with the major and extracted from the gathered corpus of job listings. The remaining topics extract skills and/or abilities from the set of job offers.

For a topic model, we used the Latent Dirichlet Allocation (LDiA) algorithm with $K = 3$ topics. For a particular major, we used the set of job offers obtained after Phase 3, Document Filtering. The algorithm was tested using monograms and bigrams. More convincing results were experimentally observed with bigrams.

The algorithm output consisted of K vectors with the latent information from the corpus which characterized the K topics. Each component of the K vectors represented the importance of each token (bigrams) from the corpus in the corresponding topic vector. In this way, we could order the tokens from the most important, in the topic vector, to the least important.

Additionally, before carrying out the LDiA model adjustment, at the moment of the Bag of Words vectorization (which is the basis of the LDiA algorithm), we eliminated all the tokens from the model whose frequencies in the corpus were below 0.05 or greater than 0.8. This was done to reduce noise (eliminating tokens without relevance in the topics) from the corpus which was automatically extracted via web scraping.

3.5 Phase 5: Concept Grouping and Profile Identification

This qualitative analysis stage was done with the aid of experts from each of the majors (or experts in the area). We used the 25 most important or relevant concepts in each of the K topics, and grouped them in order to characterize the work profile which identified this topic, given the relevant concepts.

4 Results and Discussion

In the Web Scraping phase, 749 data points associated with 468 different majors were gathered for the **Majors Corpus**. For the **Offers Corpus**, data gathering went on for 3 months, storing a total of 132,811 unique job listings.

For the Document Filtering phase, the Word2Vec and BERT models were trained with 133,560 documents (combination of both corpora). The lexicon of this document corpus contains 46,666 unique tokens. It should be mentioned that in the case of BERT, an additional pre-processor was applied to divide the tokens into even smaller tokens.

The following section presents the results of these processes for the **Psychology** major, which is given at 16 of the 18 State Universities in Chile. For this major, the **Major Corpus** has 16 different records, while the **Offers Corpus** contains 6,407 job offers covering a period from 01 June 2023 to 30 November of the same year.

4.1 Language Models Analysis for the Case Study

To study the behavior of the Word2Vec and BERT language models, we compared the vectorization for two majors with different job offers: Psychology and Agronomy. For each vectorization, we calculated the centroid of each document,

understood as the semantic average of the tokens which comprise a document, followed by applying the TSNE algorithm [13] to visualize the distribution of job openings in a 2-dimensional space. The results appear in Fig. 1.

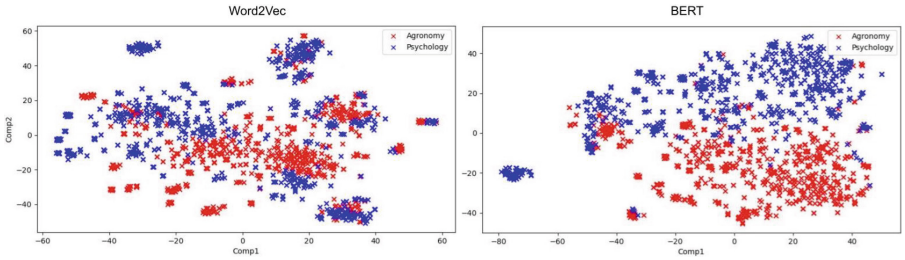

Fig. 1. 2D Plot of documents' centroids, using TSNE. (Color figure online)

Figure 1 indicates a better behavior of BERT model compared to Word2Vec. BERT (right) was able to better "understand" the difference between the job openings for Psychology and those for Agronomy, since it was almost able to separate the blue and red documents. This is not so for Word2Vec (left), which presents multiple clusters of red and blue documents mixed in with each other.

To validate the effectiveness of the filtering process, we studied variations in the number of job offers tagged within some categories (*Category* column in Table 1), before and after filtering. Table 3 presents the amount of job offers for the Psychology major.

Table 3. Number of job offers in categories, before and after the filtering procedure.

Category	Number of Job Offers		
	Pre-filtering	Post-filtering (Word2Vec)	Post-filtering (BERT)
Human Resources	61	45	60
Selection	48	32	45
Education/Teaching	11	11	11
Sales	67	16	22
Security	36	0	0

As Table 3 shows, in the categories directly associated with job openings for Psychology ("human resources" and "selection"), filtering with Word2Vec rules out some listings, but no more than 34% of them. In the same categories, the BERT filter maintains practically all the job offers. Within the "education/teaching" category, the filter with both models maintains all the job openings. In the categories which are not closely related with Psychology, like "sales",

both models discard around 77% of job offers, while in the "security" category it rules out 100% of openings.

Given the previous results, we opted to use the BERT model. In this stage, for the Psychology major, the **Offers Corpus** dropped from 6,407 to 4,314 job offers.

4.2 Topic Modeling Results for the Case Study

The next section presents the results of phase 4 for the Psychology major using the BERT model. The latent topics were calculated via the LDiA algorithm.

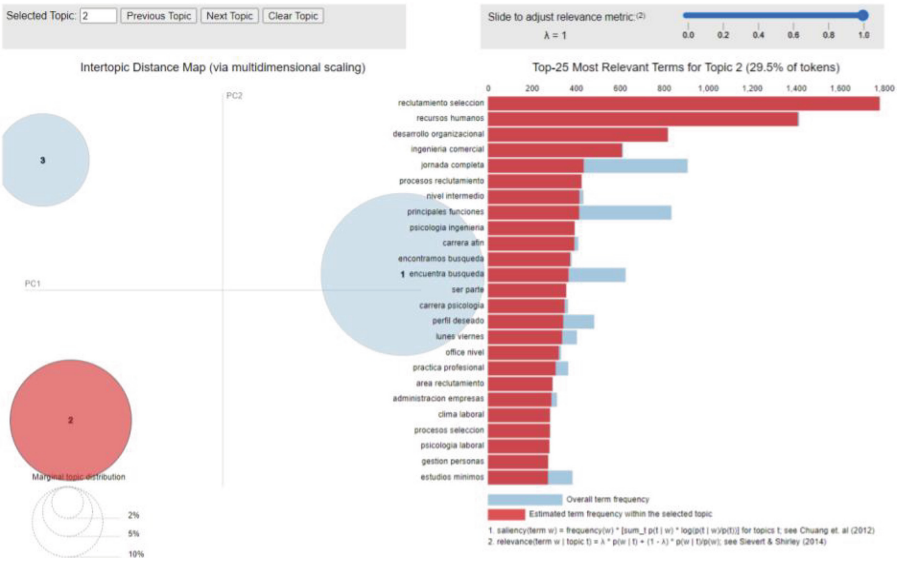

Fig. 2. Vector for work profile obtained in topic 2 (Work Psychologist).

Within the dashboards presented in Figs. 2 and 3, the left side shows a 2D projection of the 3 latent topics [18], showing that they are dissimilar topics. The right side shows the 25 most relevant concepts for a particular topic (in red). The red bars indicate the concepts' frequency (bigrams) in the topics, while the sky-blue bars indicate the concepts' frequency within the corpus. The tokens observed for each topic seem to be at first glance too general and not sufficient to capture any particular subject. However, the joint appearance of some specific concepts actually permit to experts the clear identification of different profiles on the job market.

It should be mentioned that for one of the topics extracted with LDiA, no specific profile could be identified, meaning that it was tagged as a diffuse or "noisy topic". The dashboard corresponding to this topic does not appear in the preceding figures.

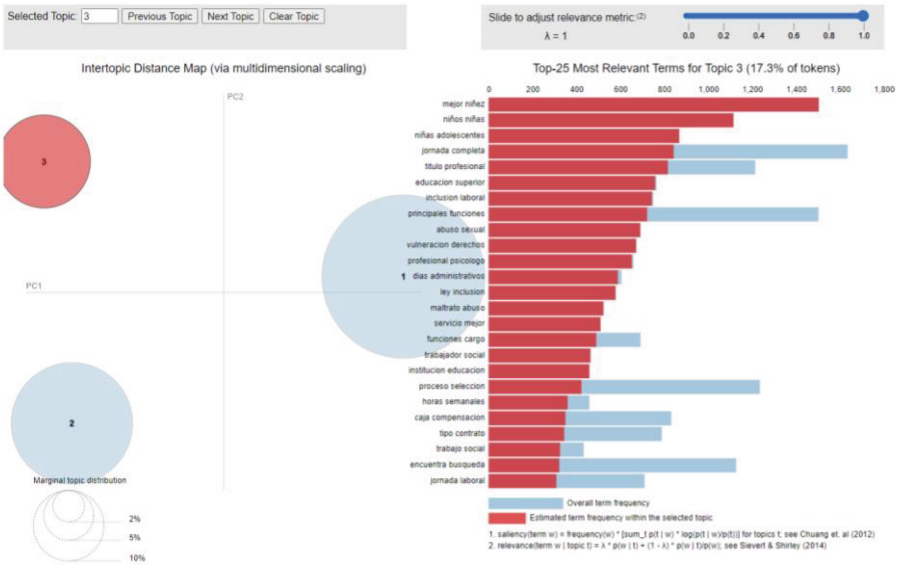

Fig. 3. Vector for work profile obtained in topic 3 (Family Psychologist).

4.3 Phase 5 Results for the Case Study

With the results presented in the previous subsection, and with the help of a total of 15 experts from Psychology majors, we were able to identify 2 work profiles based upon the 3 latent topics:

1. Noisy topic (Topic 1).
2. Work Psychologist (Topic 2), with concepts (tokens) including **recruitment selection, human resources, organizational development**.
3. Family Psychologist (Topic 3), with concepts (tokens) including **better childhood, boys girls, teenage girls, sexual abuse, rights violations, mistreatment abuse**.

All the tokens shown in the above description of latent topics actually appeared in some job offers of the corpus. Many of the other tokens not shown for each topic were classified as general concepts that appear in most job offers and therefore ignored for the interpretation of the topics.

4.4 General Case Study Discussion

With the methodology presented in this study, we obtained two clearly defined professional profiles for the Psychology major. These profiles were validated by the experts in the field, indicating that they are sought-after labor profiles in

the current market. With the additional concepts obtained via the topic model, we can identify skills and/or abilities which can complement the interpretation of each topic, including the bigrams "office level" and "intermediate level" in the case of Topic 2 (see Fig. 2) associated with the Work Psychologist profile, and "inclusion law" for Topic 3 (see Fig. 3) associated with the Family Psychologist profile.

The 3 topic vectors calculated were also projected into a 2-dimensional triangular space to visualize the job offers' closeness to each topic. We also projected the graduation profiles from some universities' case studies in the same space. Figure 4 shows the projections obtained, where the vertices of the triangle correspond to the identified topics.

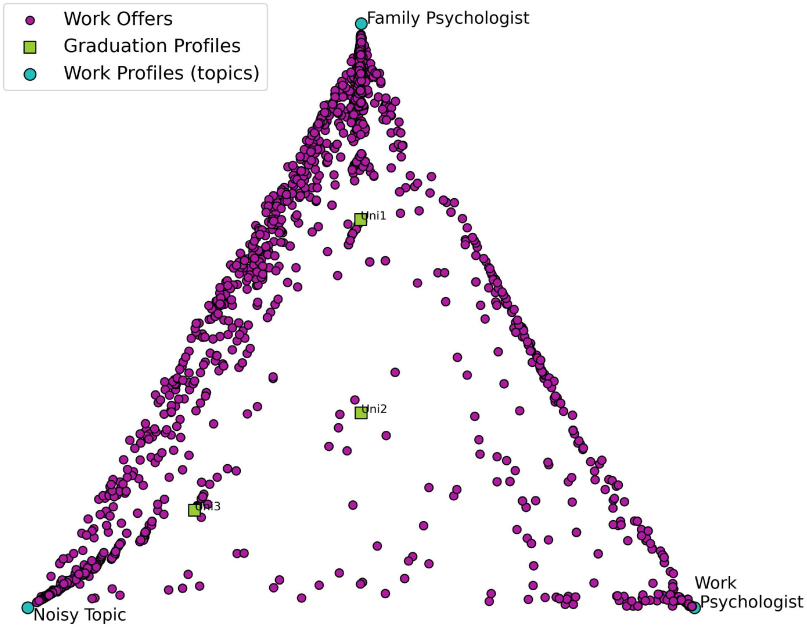

Fig. 4. Proximity of work offers and graduation profiles to the topics.

We can observe that most of the job listings are close to the Family Psychologist topic and the Noisy Topic (or diffuse). A smaller number of job offers are close to the Work Psychologist topic. We can also see that the profile for the major in Uni2 is not inclined towards any particular topic. By contrast, the graduation profiles from Uni1 and Uni3 are close to the Family Psychologist topic and the Noisy topic, respectively.

5 Conclusions

Our study presents a validated methodology which allows Higher Education Institutions to analyze the job market for a particular major in an automated, rapid, and effective way. This proposal uses consolidated NLP algorithms, including LDiA for topic modeling and BERT as a language model. The results obtained were verified for the Psychology major (case study).

The methodology has also been validated for other majors which were incorporated into the initial data gathering. In all these cases, we have been able to identify profiles and/or abilities or skills which the contemporary Chilean job market requires. However, for the correct interpretation of the latent topics, it is necessary to incorporate experts in the disciplines relevant to each career, in order to reduce bias in the interpretation.

The presented methodology can also be used to identify work profiles, abilities, and/or skills based on other dimensions, given the fields defined in the gathering process. These can include time range, Region or city, workday type, salary range, inclusiveness (for disabled people), and more.

Finally, we consider that the methodology proposed in this work has great potential to facilitate Higher Education Institutions, the redesign of curricula and reviews of graduation profiles, aspects required for their Accreditation processes.

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Assessment of the Effects of Big Data Management on Decision-Making and Business Performance

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Abstract. To understand the assessment of the effect of big data management on organizational performance and decision-making a scale was developed. Based on primary data from 407 big data users across different firms in Kinshasa, the capital of the Democratic Republic of the Congo, six dimensions or constructs that impact the relationship between big data management, decision-making, and company performance were proposed. The data for this investigation were analyzed using SMARTPLS software, and a survey was carried out. According to the survey, one of the most crucial areas for businesses to concentrate on ought to involve handling voluminous data since it gives a comprehensive understanding of the company, providing them with perspective, goals, and planning. The research's findings offer statistical proof of the beneficial relationship between big data management and decision-making and business performance. Indeed, a business that effectively handles big data may increase customer satisfaction, optimize marketing spending, forecast using information, save money, and lower risk.

Keywords: Big Data · Big Data Management · Decision-Making · Business Performance

1 Introduction

Big data-based decision making is difficult due to its primarily disorganized nature, and it may necessitate a variety of strategies, such as relational governance and contractual agreements, to fully exploit multiple data sets, both organized and unorganized. Additional labor and particular expertise are required to ensure the highest level of making decisions based on big data within the firm (Jassen 2017).

The core guiding concept of big data analytics is that by analyzing massive amounts of unstructured data from many sources, it is possible to develop actionable insights that can help businesses modify what they do to outperform the competition (Chen 2012).

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It is vital to consider data quality when collecting and interpreting data. As reported by Henke (2016), only twenty five percent of businesses believe that the handling and evaluation of big data has "significantly" improved their performance. According to a recent study, forty-nine percent of businesses feel that using big data will enhance the quality of their decisions. As a result, our key goal is to determine how big data affects the quality of corporate decisions, which in turn affects firm outcomes (Ghasemaghaei 2019).

The evolution of data today is increasing exponentially. Companies are seeking to manage information by using the vast quantities of data collected from various sources to obtain accurate and informed information from the results. The goal is to improve the decision-making process.

Furthermore, the company must put up effort and possess specialized knowledge to ensure that the greatest caliber of big data-driven decision making is made (Jassen 2017).

Enterprises that rely more on data, according to McAfee (2012), outperform one another in terms of objective criteria measuring operational and financial outcomes. When firms relied on data to make decisions at a faster rate than their competitors in their field, they were, on average, five percent more productive and six percent more profitable.

The massive amount of information generated by the internet is called as "big data" in general. Big Data affects every sector of the economy, including research, business, tourism, customer service, wellness, and education. In truth, big data does produce fresh demands, which in fact generates new jobs, just like any self-respecting digital advancement. Only businesses using data management software in the Democratic Republic of the Congo are the subject of this study.

The primary objective of this research is to develop a scale to assess how big data management affects decision-making and corporate performance. In this context, the validity and reliability studies were carried out on the data obtained from the scale.

As its primary objective, this study focused especially on the following research questions:

- Is there a relationship between the management of big data and decision-making?
- What impact does big data management have on improving organizational performance?

2 Literature Review

2.1 Big Data

Mazzoleni (2018) claims that enormous volumes of readily accessible data, both structured and unstructured, are what the literature refers to as big data. Despite the fact that this kind of information is naturally occurring since it is so common, its intricacy prevents it from being handled by traditional methods.

Important data is any data that is too big, too fast, or too complicated for today's technologies to handle. In this context, "too big" refers to the fact that organizations must manage with the gathering of pet data from devices, transaction information, click

sources, and other sources. "Too fast" suggests that vast amounts of data also need to be managed quickly (Madden 2012).

Big Data generates unique characteristics that are absent from traditional databases. These features make data analysis extremely challenging and encourage the development of new statistical methods. Unlike ordinary datasets, where the sample quantity is frequently greater than the scale, big data is characterized by vast sample size as well as elevated dimensionality (Fan 2014).

2.2 Big Data for Decision-Making

According to experts, developing capacities and competencies in information handling and big data analytics is necessary for a successful big data chain (Chen Y 2014). According to experts, developing capacities and competencies in information handling and big data analytics is necessary for a successful big data chain (Schutt 2013). Natural language processing, text mining, language computation, artificial intelligence, searching and sort algorithms, grammar and lexical assessment, and other methodologies are used as a consequence.

Decision-making quality refers to the correctness and precision of decisions. As the efficiency of information and processing improves, judgment quality may enhance or worsen (Raghunathan 1999). The accuracy and clarity with which decisions are made is defined as decision-making quality. Decision quality may improve or worsen as a result of improved data and processing quality (Sammut 2012).

Decision-makers who are aware of the linkages between the problem parts make better decisions. On the other hand, if a decision-maker does not understand the relationships, bad decisions may be made. When the people who collected and processed the data are involved, decisions are more accurate (Raghunathan 1999).

2.3 Decision-Making Quality

Companies are attempting to discover the optimum strategy to using information for decision making in the present big data era (Shamim 2019). Combining managerial skills with business information technologies might help you make better decisions. Decision-making efficacy can be judged by how satisfied decision-makers are with the achievement of their targeted aims. The success of a decision is determined by the resources used, such as time, money, and so on.

According to Li (2022) decision-making perfection refers to the regularity and correctness of the outputs, which are measured throughout the process of making decisions by the utility of decisions and decision productivity (Aydiner 2019). According to (Shamim 2019) Decision utility is concerned with the accuracy, precision, and dependability of the chosen outputs, whereas decision efficacy is concerned with the length, costs, and other elements of the resources involved. Users' diverse desires, as well as the advent of public concerns such as COVID-19, have raised expectations for firms' decision-making abilities (Pham 2018).

2.4 Decision-Making Performance

According to current literature, decision-making capacity is examined in relation to decision-making duration and choices correctness (Speier 2003). As a result, it considers both energy consumption and precision. Some researchers investigated decision-making competency through a broader lens, viewing it as an issue of both effectiveness and productivity (Visinescu 2016).

The approach of Visinescu (2016) was complemented by (Shamim 2019), which discussed how efficient and success of decisions in relation to big data-driven decisions. Large-scale data usage refers to the creation of useful information from vast amounts of data (Elia 2019).

Generating data-driven decisions means relying solely on the information at hand rather than generating assumptions. Big data improves decision effectiveness and allows organizations to make well-informed judgments (Jassen 2017).

Using big data in order to make decisions is one of the important aspects for achievement in the modern economy, according to the literature (McAfee 2012). Although some big data skills are required for substantial data-driven judgments (Shamim 2019).

2.5 Organizational Performance

Organizational performance is a term that refers to a detailed assessment of a company's successes as well as the long-term viability and quality of its operations (Ghasemaghaei 2018). Several studies in the IS literature have focused on the benefits associated with business information technology and its success. Organizations with outstanding IT capabilities, for example, outperform rival organizations in terms of expenses and profitability, according to Bharadwaj (2000).

Increasing operational effectiveness is a critical goal in the big data era since it provides businesses with a competitive advantage (Martin 2017). Big data analysis reveals trends that help firms generate more goods and services, provide better internal and external client care, and run more efficiently when compared to similar rival enterprises (Wu 2015). This could help firms gain a competitive advantage. Furthermore, it has been claimed that an organization's capabilities (such as handling vast volumes of data, analytical skills of staff members, and the sophistication of its tools) may aid to enhance business performance (Liberatore MJ 2017).

3 Methodology

The aim of this study was to develop a Likert- type scale to assess how big data management affects decision-making and corporate performance of big data users. The scale consisted of 6 dimensions and 24 items and it was created through Google Forms, and the link was distributed to the participants via email and social media.

3.1 Participants

The 407 employees of different companies in Kinshasa, the capital of the Democratic Republic of the Congo, who use big data to make choices and improve business performance participated in this study. Chain-referral sampling strategies, also known as

purposive and snowball sampling were used to collect the sample for this study. Participants included both men and women; 63.1% of respondents were men and 34.3% were women.

3.2 Hypothesis Development

The purpose of the current study is pursued through hypotheses. The suggested hypotheses are described below:

- H1: The quality of data sources is favorably correlated with big data technology.
- H2: Performance and an organization's culture are strongly related.
- H3: Effectiveness and efficiency of decision-making are connected.
- H4: The efficacy of decision-making has a beneficial relation with the culture of an organization.
- H5: There is a significant relationship between decision-making efficiency and an organization's culture.
- H6: Performance and the quality of the data source are linked.
- H7: The efficacy of decision-making relates to organizational performance.
- H8: Effective decision-making contributes to organizational performance.

3.3 PLS-SEM Model

A scale has been developed by creating a questionnaire. The questionnaire consists of 6 dimensions (technology of big data, organizational culture, decisions-making effectiveness and efficiency, quality of data, performance) and 24 questions. Our hypotheses are based on these 6 dimensions. A total of 407 responses were received, enabling to develop the PLS-SEM model for analysis. PLS-SEM MODEL has become a typical method for analyzing complex connections between observable and latent variables in social science research.

Figure 1 represents the extensive relationships between the dimensions and their items.

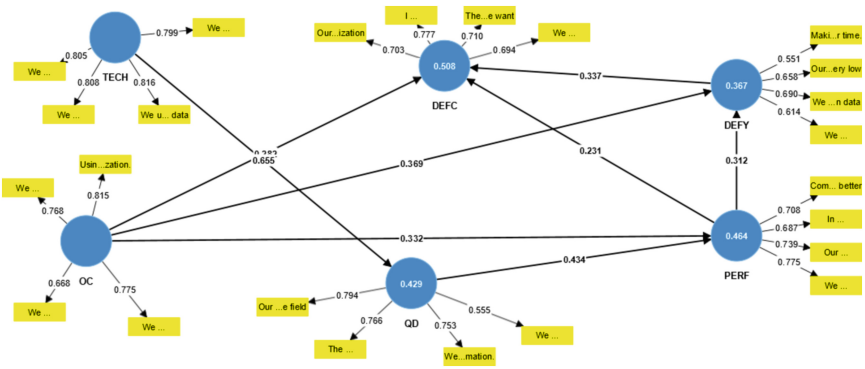

Fig. 1. PLS-SEM Model

4 Results

4.1 Dimensions Reliability and Validity

Similar to how diabetes specialists value precision in patient care and medication, researchers value precision in their findings. Precision is linked to dependability and repeatability. Reliability denotes the ability to measure something consistently. Validity implies that you are precisely measuring what you intend to measure. A simple assertion that something is legitimate may be worthless unless it specifies the type of validity under consideration (Fitzner 2007).

Each dimensions' Cronbach's alpha was used to rate the dependability of the structures. We employed the composite reliability (CR) and the average variance extracted (AVE) to test validity (Table 1).

Table 1. Dimensions Reliability and Validity

Dimensions	Cronbach's alpha	Composite reliability (CR)	Average variance extracted (AVE)
TECH	0.822	0.882	0.651
OC	0.752	0.843	0.575
DEFC	0.693	0.813	0.521
DEFY	0.501	0.724	0.398
QD	0.692	0.812	0.523
PREF	0.703	0.818	0.529

Source: Authors' calculation with Smart PLS

4.2 Discriminant Validity

The degree to which measurements produced by a measuring paradigm vary in a way that signals that its execution could possibly be catching features of other ideas is referred to as discriminant validity. Assessing a particular idea and viewing another should only correlate to the degree that the two constructs are linked. As an exception, if two structures are completely unrelated, there should be no correlation in their values. When an idea is linked to numerous other constructs, proving the veracity of discrimination can be extremely difficult (Aydiner 2019) (Table 2).

Table 2. Discriminant Validity

	DEFC	DEFY	OC	PREF	QD	TECH
DEFC						
DEFY	1.010					
OC	0.829	0.876				
PREF	0.819	0.875	0.792			
QD	0.804	0.810	0.779	0.888		
TECH	0.761	0.853	0.786	0.758	0.849	

Source: Authors' calculation with Smart PLS

4.3 Hypotheses Result

This study applies SMART PLS path analysis to investigate various assumptions. Figure 1 of the PLS-SEM Model depicts the connections between the various dimensions. The bootstrapping method's path coefficient (β) and P value computations were used to determine the importance of the pathways.

Table 3-a displays the path of analysis results. H1 'Technology of big data significantly related with Quality of data source' shows a positive correlation between technology and data quality (=0.655, p0.01). H1 is approved.

'An organization's culture has a good relationship with performance,' says H2. The findings reveal that organizational culture is related to performance (=0.332, p0.01). H2 has been accepted.

H3 'Decision-making Efficiency is related to Decision-making Effectiveness'. The results show that decision making efficiency is related to decision making effectiveness (=0.337, p0.01). H3 is accepted.

'An organization's culture has a good relationship with decision-making effectiveness,' says H4. The results reveal that organizational culture is related to decision-making efficacy (=0.282, p0.01). H4 is accepted.

'An organization's culture has a good relationship with decision-making efficiency,' says H5. The results reveal that organizational culture is associated with decision-making efficiency (=0.369, p0.01). H5 is accepted.

H6 'Data source quality is favorably related to performance'. The results show that data quality is positively related to organizational effectiveness (=0.434, p0.01). H6 is accepted.

'The organization's performance has a good relationship with decision-making effectiveness,' says H7. This indicates that performance is related to decision-making effectiveness (=0.312, p0.01). H7 is accepted.

'The organization's performance has a good relationship with decision-making efficiency,' says H8. This indicates that performance is related to decision-making efficiency (=0.231, p0.01). H8 is accepted.

The result shown in the Table 3-b, is the difference between the correlation coefficient and the path coefficient.

Table 3-a. Hypotheses Test Result

Hy-potheses	Path	Coeffi-cient(β)	T statistics	P values	Result
H1	TECH->QD	0.655	13.957	0.000	Supported
H2	OC->PERF	0.332	5.151	0.000	Supported
H3	DEFY->DEFC	0.337	6.530	0.000	Supported
H4	OC->DEFC	0.282	5.123	0.000	Supported
H5	OC->DEFY	0.369	5.779	0.000	Supported

Source: Authors' calculation with Smart PLS

Table 3-b. Indirect effect

Tested Path	Coefficient(β)	T statistics	P values
TECH->DEFC	0.096	3.579	0.000
TECH->DEFY	0.089	3.650	0.000
TECH->PERF	0.284	6.084	0.000
OC->DEFC	0.236	6.498	0.000
OC->DEFY	0.104	3.586	0.000
QD->DEFY	0.135	4.064	0.000
QD->DEFC	0.146	3.999	0.000
PERF->DEFC	0.105	4.047	0.000

Source: Authors' calculation with Smart PLS
Note: '*' = p < 0.01

4.4 Descriptive Statistics

The average of a set of scores is called the mean. The total score was divided by the total number of scores. Extreme scores might affect the mean when population samples are tiny.

The standard deviation is a metric that indicates the degree of deviation from the mean. A "normal" variation from the mean is indicated by the standard deviation. Because it goes back to the data set's initial units of measurement, it is a well-liked measure of variability.

The questionnaire data was evaluated using descriptive statistics to determine how the handling of large amounts of data has influenced decision making and company choices. Tables 4 and 5 results indicates that the data are spread out over a large range of values.

Table 4. Mean and Standard Deviation of items

Items	Means	Std Dev
Technology		
We use the most recent technologies to manage large data.	3.941	0.913
We use software to analyze massive data.	4.145	0.874
We use cloud-based services for processing data and performing analytics.	3.894	0.963
We use an assortment of technology techniques to manage big data.	3.916	0.977
Organizational culture		
We base our decisions on data rather than on intuition.	4.325	0.922
We are strongly discouraged to depend only on intuition when making decisions.	4.079	0.936
We work in a data-driven culture.	4.382	0.882
Using data is a common activity for our organization.	4.429	0.79
Decision-making effectiveness		
We make wise judgments, in my opinion.	4.222	0.871
Our decisions enhance the effectiveness of the organization.	4.165	0.871
The decisions we make lead to the results we want.	3.943	0.803
I am satisfied with the outcomes of our decisions.	4.296	0.849
Decision-making efficiency		
We take prompt action.	3.921	0.972
Our decision-making cost is very low.	3.84	0.993
We make judgments based on data.	3.97	0.904
Making decisions takes a lot of our time.	3.133	1.158
Quality of data		
We get reliable data from our major data sources.	3.549	0.807
The quality of the data given by our big data sources has satisfied us.	3.751	0.809
We efficiently manage difficult data and information.	4.325	0.914
Our big data suppliers are well regarded in the field.	3.793	0.905
Performance		
Our work increases customer satisfaction.	4.126	0.782
We deliver higher-quality goods and services.	4.401	0.812
Comparing our profit growth rates to those of our competitors, we do substantially better.	3.823	0.878
In terms of profitability, we surpass our competitors.	3.823	0.898

Source: Authors' calculation with Smart PLS

Table 5. Mean and Standard Deviation of dimensions

Dimensions	Mean	Standard Deviation
Technology	3.983	0.749
Organizational culture	4.321	0.666
Decision-making effectiveness	4.158	0.612
Decision-making efficiency	3.795	0.627
Quality of data	3.874	0.632
Performance	4.065	0.61

Source: Authors' calculation with Smart PLS

5 Discussion

Big data has the potential to transform the innovation environment by improving the relationship between customer needs and offerings in a successful and effective way, possibly enhancing business performance as well. The use of big data supports in exploring more of the 'why' of situations clarified by conventional statistical methods in order to improve data evaluation, which considerably aids in enhancing firm decision quality. As a result, businesses started to analyze big data in order to improve their decisions.

The research introduces new theoretical viewpoints. This study shows that each dimension (technology, organizational culture, quality of data, performance and decision- making efficiency and effectiveness) of big data management have different impacts on decision-making and business performance results.

The study concentrated on the factors influencing the quality of decision making in response to Jassen (2017). All eight of the presented theories received support. Similar to Shamim (2019) earlier work, which developed a construct of big data management and examined how decision-making may enhance big data management and promote company performance, the findings likewise show how big data management enhances business outcomes.

The outcomes of Ghasemeghai (2019) work demonstrate that big data positivity enhances firm decision quality also the results of this investigation indicate a strong correlation between technology and data quality.

Additionally, the results show that organizational culture has a favorable correlation with productivity decisions are positively connected with results in data-driven societies. There may be a stronger cultural connection between the inclination to act than to perform. McAfee (2012) supports the idea that there is a cultural correlation between data usage.

Businesses in the big data era of today cannot prosper merely by having access to high-quality data; instead, they must have competent management, an organized strategy, and most importantly, an organizational culture that supports the use of big data and decision making.

The study analyze shows a positive relationship among both the efficiency and effectiveness of huge-data decisions. An organization's decision-making procedure enhances its effectiveness and efficiency. The degree of decision-making is impacted by the quality

of data sourced, how it is processed, and the way it is delivered. The aforementioned findings highlight how crucial it is to develop appropriate and effective economic and interpersonal governance strategies for overseeing the supply chain (Jassen 2017).

This study provides a big data and decision-making management model that can be compared to various management and performance techniques to investigate the antecedents of big data decision-making capabilities. In the context of big data, this study contends that data practices and data management are more significant than data science for improved big data decision making.

6 Conclusion

The object of big data management is to use large information and statistical methods to provide applications with unprecedented levels of data quality and accessibility. Big data management solutions are being used by businesses, governments, and other organizations to control the growing volume of data. Data that can be measured in terabytes or even petabytes and is stored in a number of formats.

In summary, the intent of this research is to produce a scale to evaluate assessment of the effects of big data management on decision-making and business performance. These management techniques affect the company's potential for using large amounts of data for making decisions, assisting firms to make knowledgeable and prompt actions.

An online survey with 407 participants was used to collect data from employees of a Congolese firm. Several previous studies have shown that big data management has an impact on corporate performance.

Data management is one of the most important areas for businesses to focus on since it provides managers with a holistic view of the company, which aids in perspective, objectives, and planning. The current research aims to create a scale to assess how big data management affects decision-making and corporate performance. The findings demonstrated that each dimension has an impact in the decision making and performance of firm.

These approaches have an impact on a firm's big data decision-making competence, allowing it to make effective and efficient judgments. A good management of big data may boost customer happiness, improve advertising expenditures, forecast with knowledge, minimize expenses, and reduce risk.

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Virtual Reality for the Support of School Teaching in the History Course

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Abstract. The article presents a virtual reality web application to enhance the teaching of history in high school students in Lima, Peru. It emphasizes the significance of supporting school teaching in light of the suboptimal educational outcomes in Latin America, as reflected in tests such as PISA. The state-of-the-art reviews virtual and augmented reality systems applied to education, such as games, simulations, and immersive environments. The motivation is the absence of a standard methodology to design effective VR experiences in education. The objective is to develop a web application with VR to improve the teaching of history in a school in Lima. The EduVR method is proposed, which uses the FrameVR platform to implement VR, with a client-server architecture and solid backend.

The validation was performed with a case study in two groups of 15 students, one with traditional classes and the other additionally with VR. The VR group demonstrated an increase of 4 points on the exam versus 1 point without VR. The application was found to be easy to use by 93% of respondents, and 100% considered it very useful for learning. The main contribution is the EduVR method, which integrates VR to improve education. It can be concluded that the VR web application, when used in conjunction with traditional education, allows for a better understanding and retention of historical knowledge.

Keywords: virtual reality · education · teaching · history · methodology

1 Introduction

1.1 Context and Importance

A number of recent studies on effective teaching methods have highlighted the importance of incorporating active learning in the classroom. According to [1], strategies such as project-based learning, active learning, and guided inquiry promote deeper engagement and learning than traditional lectures. In [2], frequent and specific feedback to students about their work has a significantly positive impact on their learning and academic performance. When feedback provides clear information on how to improve, rather than just pointing out errors, its effect is even greater. The timing of feedback is also crucial,

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with the greatest impact observed when it is provided in close proximity to the completion of the task. Both verbal and written feedback, whether provided by teachers or peers, has been demonstrated to have a positive impact. This meta-analysis highlights the crucial importance of implementing effective feedback practices to enhance student learning. In [3], the 2018 PISA test results show that students in Latin America perform poorly compared to the global average. In [4], the scores obtained by the countries of the region were notably inferior to those of Asian countries such as China and Singapore, which were recognized as having the world's most advanced educational systems. Chile and Haiti exhibited the highest and lowest scores, respectively. The mean scores for 15-year-old students in the region were 379 in mathematics, 413 in science, and 405 in reading. These scores indicate a learning crisis in the region. One of the technologies that merits particular attention with regard to educational methodology is virtual reality, which has become an increasingly popular tool in school teaching. In [5], it was demonstrated that the use of virtual reality can significantly enhance students' learning in history by enabling them to explore and experience historical events in a more immersive and engaging manner.

1.2 Motivation

A review of existing studies in the field of VR reveals a wide variety of applications and technologies. However, despite this diversity, no standard methodology has been identified for the systematic design and evaluation of effective VR experiences. Despite the advances that have been made in the areas of interaction, simulation, and immersion, the lack of clear objectives and the non-optimization of VR experiences have hindered their widespread use and impact on society.

1.3 Novelty

The novelty of this proposal lies in the integration of advanced techniques, such as interactive simulation and the implementation of 360-degree images, which offer an immersive and participatory experience for students. In addition, the priority of designing a platform that is easy to access and use is highlighted, with the purpose of making the adoption of virtual reality technology accessible and user-friendly for all users involved in the educational process. This novel and diversified approach represents a significant advance in the implementation of VR technology in education.

1.4 Purpose/Objective

The objective of this contribution is to provide support for teaching in the school environment. The general objective is to develop a web application assisted by virtual reality to provide 5th year high school students with a reliable documentation that will be analyzed, designed, and validated. This will result in effective results with respect to student teaching.

1.5 The Main Contribution

The article is comprehensive, drawing upon the existing literature on VR to provide a detailed analysis of the pedagogical applications of VR in the context of school teaching. It offers a set of experiences and insights that facilitate a deeper understanding of the subject matter and validate the satisfaction derived from the interactive applications. The Frame VR development platform was selected for its ability to function across multiple platforms and browsers, regardless of the device's WebVR capabilities. This platform will be implemented and validated at the Emmanuel school in the district of Villa El Salvador.

1.6 Organization of the Article

The main objective of the project, entitled "Virtual Reality Web Application to Support School Teaching," is to revolutionize the teaching process in the Peruvian context through the incorporation of modern technologies, specifically virtual reality. The purpose of this project is to create an interactive educational tool that provides Peruvian students with an immersive, stimulating, and highly effective learning experience that fosters a deep understanding of concepts and promotes interest in learning. The following components will be developed for the system:

Virtual Reality (VR) Platform: The project's primary focus is the development of a VR platform accessible via the web. This platform will enable students to access a virtual environment that simulates realistic educational situations and interactions with 3D models of abstract concepts. VR will provide a high degree of immersion and engagement, which will enhance knowledge retention and understanding of topics.

Interactive Educational Content: An indispensable element of the proposed virtual reality web application is the inclusion of interactive educational content. This content will be specifically tailored to align with Peruvian educational standards and address key historical concepts. It will utilize both visual and aural elements to facilitate the comprehension and engagement of students.

Assessment and Feedback Tools: To ensure the effectiveness of the learning system, assessment and feedback tools will be incorporated. These will enable educators and students to monitor their progress and understanding of the topics.

Teachers will be able to generate personalized assessments and receive detailed reports on student performance, which will assist them in adjusting their teaching methods according to individual needs.

Accessibility and Equipment: Given the challenge of accessibility in many school contexts in Peru, special attention will be paid to ensure that the application is easily accessible via computers.

Together, these components will enable the creation of a virtual reality web application that addresses educational challenges in Peru, improves the quality of teaching, and fosters a more engaging and effective learning environment for students.

A review of the literature on virtual reality in education reveals that this technology has the potential to significantly enhance teaching and learning.

2 Related Work

In [6], a study was conducted to investigate the impact of augmented reality on the academic performance of chemistry students, including those with special educational needs. A quantitative approach was employed to examine 60 participants, and significant improvements in immediate performance and content retention were identified. Augmented reality (AR) is identified as an inclusive and sustainable tool that can enhance social and cognitive justice in education, preparing students for a dynamic future. In [11], a prototype of an application that employs virtual reality technology to assist children with autism in their educational endeavors was presented. The application was developed with consideration of the profile of children with autism, as outlined in the Autism Guide, to ensure that it possessed user-friendly features. This was validated by experts in media and autism, and the application achieved an evaluation rating of 87.3/100.

In [12], Emo FindAR is proposed as a game to improve socialization, communication skills, and emotional intelligence in elementary school children. This game intensifies student interest through competitive or collaborative activities and also uses augmented reality. In [14], an immersive reality didactic tool is developed that creates a virtual environment based on images to visualize graphics and that allows adding information to the images to interact with the user. A study with 50 students validated the platform, which was then introduced in an Italian architecture class. User satisfaction was evaluated through the experience of virtual reality scenarios (360 degrees) related to the subject. In [15], a study was conducted that designed, implemented, and evaluated a VR-based immersive educational game to teach topological relationships to high school students. Thirty-seven male students participated, and four questionnaires were used to evaluate the effectiveness of the proposed learning environment. The findings indicated that students perceived the solution to be beneficial and efficacious within the educational setting.

3 State of the Art

The implementation of virtual reality in educational environments has emerged as a promising tool for transforming the learning experience. In general, a virtual reality system for school education comprises several essential components that contribute to enriching the educational process. These components include immersion in simulated environments, high-quality interactivity, and personalization of learning.

Component 1: Immersion in Simulated Environments

Immersion in simulated environments is a key pillar of virtual reality in education. As Huang et al. observe, “Virtual reality immerses users in virtual worlds, providing a highly immersive experience that can significantly enhance knowledge comprehension and retention” (Huang, W., et al. 2019). This feature allows students to explore three-dimensional environments and live experiences that would otherwise be inaccessible, offering a more hands-on approach to learning.

Component 2: High-Quality Interactivity

Another key feature of virtual reality in education is high-quality interactivity. According to Chen et al., “The ability of users to interact with virtual environments,

manipulate objects, and receive immediate feedback enhances participation and engagement with educational content" (Chen, A., et al. 2018). This dynamic interaction allows students to actively experiment in a hands-on manner, which fosters a deeper and more significant understanding of concepts.

Component 3: Personalization of Learning.

The capacity to personalize learning is a crucial attribute of virtual reality in education. As Engel and Coll observe, "Virtual reality enables the adaptation of educational content to align with the individual needs of learners, thus facilitating more personalized and effective learning (Engel, A., & Coll, C. 2022). This entails adjusting the content and learning scenarios according to the pace and learning style of each student, which can enhance their motivation and comprehension.

The educational content addressed by the use of virtual reality encompasses a diverse range of disciplines, including scientific exploration in biology and chemistry, historical reenactment, and event simulation in the humanities and social sciences.

A Low-Cost Interactive Writing Board for Primary Education using Distinct Augmented Reality Markers: This study concentrated on the development of a low-cost interactive writing board for primary education utilising augmented reality markers. The outcomes demonstrated that the board considerably enhanced students' capacity to learn to write.

Design, implementation, and evaluation of an immersive virtual reality-based educational game for learning topology relations at schools: A case study.

This study focused on the development of a virtual reality educational game for learning topological relations in schools. The results demonstrated that the game significantly enhanced students' comprehension of topological relations.

The Use of Virtual Reality in Geo-Education This study focused on the use of virtual reality in geographic education. The experiment lasted from September 2019 to December 2019 and involved 60 third-year students from Abai Kazakh National Pedagogical University (Kazakhstan), Immanuel Kant Baltic Federal University (Russian Federation) and Aldar University College (United Arab Emirates). The results demonstrated that the use of virtual reality was associated with the desired quality of the educational product.

4 Contribution

The EduVR method proposes to enhance the quality of hybrid education in Lima through an interactive educational experience based on virtual reality (VR). The method is based on a client-server architecture, where the client is the web application and the server is a dedicated cloud environment. It employs the FrameVR platform to implement virtual reality and leverages a robust backend for online services, including APIs, storage, and authentication.

The components of the approach are: The client-server architecture is comprised of a web application acting as the client and a dedicated cloud environment functioning as the server. The robust backend provides essential online services, including API, storage, and authentication. The FrameVR platform is utilized to create virtual tours and

panoramic photos, offering an immersive experience for students. Additionally, the platform allows for flexibility in linking additional content. The incorporation of additional content through virtual reality technology allows for the deepening of study topics and the improvement of test phases. Historical study, the identification of panoramic images, and the creation of virtual tours are included to ensure the quality and authenticity of educational content. The API facilitates the collection, creation, and modification of content, improving the efficiency of the workflow for teachers and students.

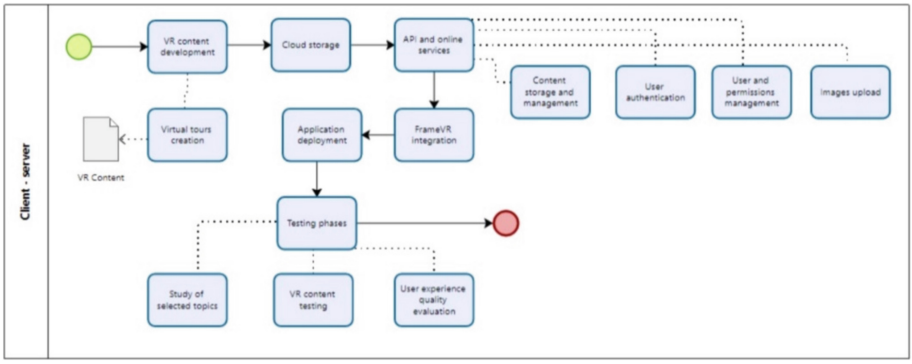

Fig. 1. Description of the proposed design input process. Based on Puggioni et al. (2021).

Figure 1 delineates the methodology, with a particular emphasis on VR as the central technology. This is based on a series of testing phases and the requisite online services, including API, storage, and authentication. The core component of the VR experience is a robust backend, which allows for the linking of additional content through this technology. In conclusion, EduVR endeavors to enhance the quality of hybrid education in Lima by providing a more interactive and visually engaging educational experience, with a focus on hands-on exploration of scientific concepts through virtual reality.

5 EduVR

5.1 Architecture

The implementation of the "EduVR" solution, an innovative platform designed to provide immersive learning experiences through virtual reality technology, is described. The EduVR solution is developed using the Frame VR platform, which combines the Frame concept, representing the structure and context of learning, with the VR element, reflecting the platform's focus on educational immersion.

5.2 Technological Architecture

Figure 2 depicts the architectural diagram, which commences with users interacting with a computer or mobile device. These devices must be connected to the internet before they

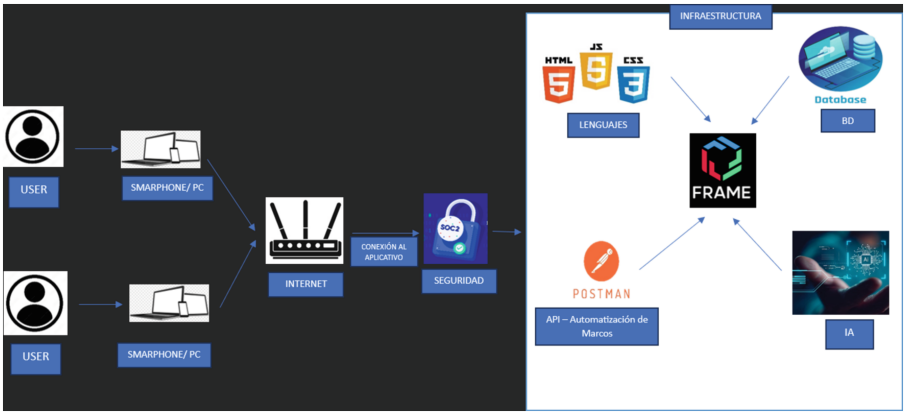

Fig. 2. User - application deployment architecture

can enter the "Frame VR" application. This application requires users to pass the security of the SOC2 application, which requires them to enter an email address and verify it. In terms of the development of the application, it is comprised of three distinct languages: HTML, JavaScript, and CSS. These languages are aided by artificial intelligence and a database, which are ultimately linked to the API Rest called "Frame Automation".

5.3 Development

This paper describes the implementation of the EduVR application, including the languages and libraries used for its deployment.

Language, Libraries, Environment

The Frame VR application is deployed under the following programming languages:

- C++: The fundamental components of the platform are constructed in C++, a language renowned for its high performance and efficiency.
- Python: The development environment for FrameVR is written in Python, which provides the application with scalability.
- JavaScript: The FrameVR Software Development Kit (SDK) for web browsers is written in JavaScript, thereby ensuring broad cross-device compatibility.
- OpenXR: The open virtual reality standard that FrameVR employs in order to ensure broad compatibility.
- Vulkan: The modern graphics API that FrameVR employs in order to provide optimal and efficient performance.
- Unity: The 3D game engine utilized by FrameVR to generate virtual reality experiences.

5.4 System

Functionality

Frame VR has different features which make its functionality enjoyable and optimal for the user:

- Social: Frame users have many communication and collaboration tools. For example: voice chat, text chat, web cams, emojis, etc.
- Code-free customization: Frame allows users to expand their creativity within a spatial canvas, using the drag-and-drop editor to create amazing spatial websites.
- Scalable: Frame is ideal for small meetings or mass events; you can have up to 1000 people in the same frame.
- Presentation Tools: Frame has typical tools such as webcam sharing, screen sharing, uploading PDF files, but also some special ones such as switching between "scenes", the 3D version of a PowerPoint presentation.
- Graphics: The user will be able to use his own 3D environments and models or the same Frame VR environments.
- Artificial Intelligence: Generation of functions such as chatbot with GPT technology, text translation in 30 languages, among others.
- API Developer Tools: The Frame API allows developers to manage and customize their Frames from a simple REST API, the API is called Frame automation.
- Security: Privacy and security will have SOC 2, which is a report based on the auditing standards of the American Institute of Auditing Standards Board.

Application Interface

Fig. 3. Interface with a player in the created scenario

Figure 3 depicts one of the frames of the Frame VR application. This application allows users to view a variety of media, including images, videos, and 3D images, on the subject of terrorism in Peru. In this instance, the single player can navigate through the media presented in the "Exhibition Lounge," which is a virtual museum with a multitude of images. The images displayed in this context are related to the subject matter being discussed. Additionally, surround sound has been incorporated into the system, allowing users to adjust the volume of the audio according to their proximity to the video.

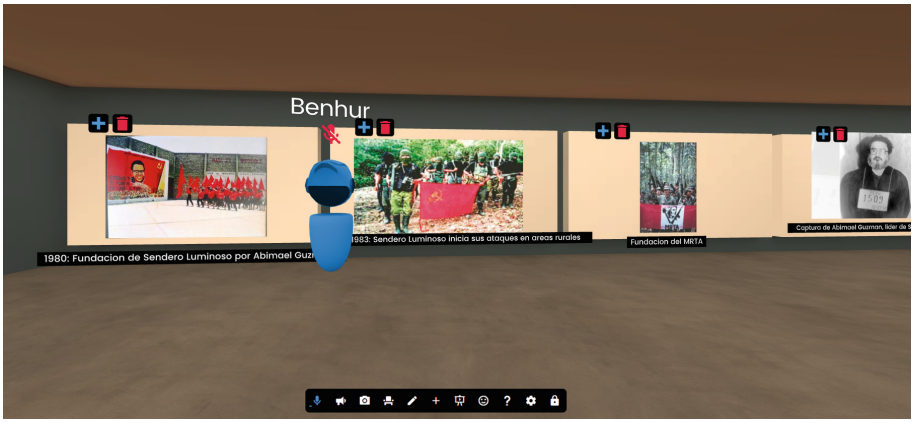

Fig. 4. Interface with different players

Figure 4 shows the "School" scenario, which employs the theme of terrorism in Peru. It presents a variety of visual elements, including images in different formats (e.g., jpeg, gif, png, bmp). In this instance, the interface is displayed with two users, demonstrating the scalability of multiuser interaction within a single scenario.

6 Validation

6.1 Case Study

The web application was validated at the Emmanuel school in Villa el Salvador. It was tested with two groups of 15 students, each of whom was in the fifth year of high school and was enrolled in the history course, which was taught by the same instructor.

In order to conduct a case study to validate the implementation of virtual reality in the history course, a series of essential elements are required for the comparison between the group that will use virtual reality and the control group. These elements include:

Equal Number of Students
Age: The selected group of students are aged between 15–17 years old.

Score in the Past Period: The minimum and maximum grade of the students in the History subject in the previous period will be recorded for both groups.

History Topic: A specific history topic was selected and addressed by both the virtual reality group and the control group. In this case, the topic chosen according to the assigned curricular content was "terrorism in Peru during the 1980s and 1990s".

Evaluation: Prior to the implementation of virtual reality, an initial evaluation was carried out in both groups to measure their knowledge of the selected topic. This included a questionnaire related to the chosen topic. After implementation, a second evaluation was conducted to measure the impact of the use of virtual reality on the knowledge acquired by both groups. This evaluation was conducted in a similar manner to the initial one to allow a direct comparison.

Usability Survey: To gather information on the usability, experience and usefulness of virtual reality in the educational environment, surveys will be conducted with both teachers and students. The teacher survey will assess the ease of integration of virtual reality into the curriculum, effectiveness in teaching, and challenges encountered in its implementation. The student survey will address the learning experience, the perceived usefulness of virtual reality in understanding the historical topic, and their comfort with the technology.

6.2 Adaptation of the Rules

The content of the interactive virtual reality simulations will be adapted to the Peruvian national curriculum for the History course in the fifth year of secondary school. Different topics related to the chosen theme were considered.

The simulations will allow students to interact in a 3D and immersive environment to better understand the concepts and events.

To ensure that virtual reality is effectively integrated into the educational environment, several rules were applied that may require adaptation:

1. Educational content: It is necessary to review the History curriculum content and determine how virtual reality can be effectively integrated into existing lessons. This involves identifying the historical topics that benefit most from immersion in virtual reality.
2. Assessment: Assessment strategies should be tailored to measure not only the knowledge acquired, but also the ability of students to interact and make decisions within virtual environments.
3. Teacher training: Teachers who will use virtual reality in the classroom will require specialized training to take full advantage of the technology. This includes training in the use of the FrameVR platform and in the creation of effective learning experiences.
4. Infrastructure and resources: The school infrastructure needs to be adapted to support virtual reality technology, including the availability of hardware and software, as well as the management of technical resources.

6.3 Experimentation

Two groups of 15 students each were formed.

Group A (Control): received 3 sessions of traditional 2-h classes on Terrorism in Peru.

Group B (Experimental): received the same 3 sessions of traditional classes. In addition, they used the VR web application in a 1-h session during the aforementioned week.

The application included an immersive simulation of the events of terrorism in Peru during the 1980s and 1990s (Fig. 5).

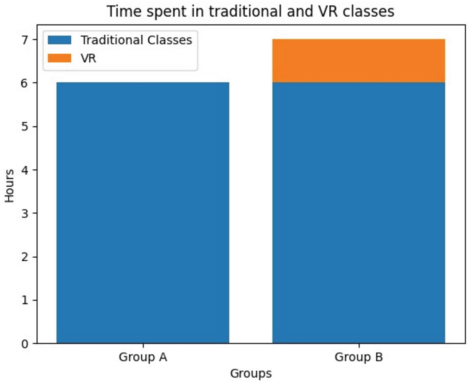

Fig. 5. Bar chart illustrates the proportion of hours dedicated to traditional classroom instruction and the integration of virtual reality.

6.4 Metrics

Academic Performance
Both groups were evaluated with a 20-question test on the subject matter before and after the intervention. The mean grades of each group were compared.

Satisfaction (Group B Only)
A survey was administered to assess the perceived ease of use and usefulness of the intervention on a Likert scale (2008) from 1 to 5.

7 Results

As illustrated in Fig. 6, the students in Group A, who received only traditional classes, achieved an average score of 14 on the pre-intervention exam and an average score of 15 on the post-intervention exam. This represents a mere 1-point improvement in their academic performance.

In contrast, group B, which utilized the virtual reality web application in conjunction with traditional classes, exhibited an average grade of 14 on the initial exam and an average grade of 18 on the final exam following the intervention. Consequently, this group demonstrated a 4-point improvement in their academic performance, a considerably higher result than that of the control group.

This difference illustrates that immersion in virtual reality simulations on the subject of terrorism in Peru, in conjunction with traditional education, enables students to more effectively reinforce the concepts and information imparted in the classroom. Interactivity and experiential learning within virtual scenarios have a positive impact on the comprehension and retention of knowledge regarding this historical topic.

Group A: The initial grade point average was 14, while the final grade point average was 15.

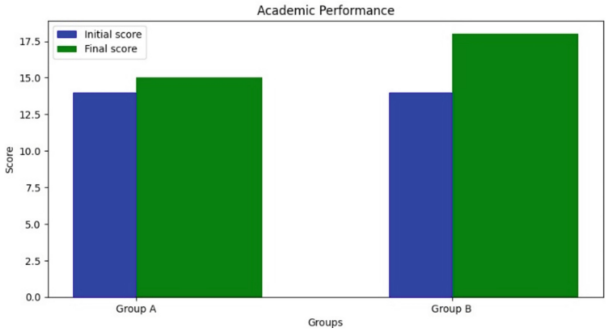

Fig. 6. Bar graph illustrates the academic performance outcome before and after the implementation of virtual reality.

Group B: The initial grade point average was 14, while the final grade point average was 18.

With regard to the satisfaction survey conducted with Group B, it was found that the virtual reality web application was highly accepted (see Fig. 7). Ninety-three percent of the students indicated that they found the interface intuitive and the controls natural.

Similarly, all members of group B (see Fig. 7) rated this technology as "highly useful" for learning about terrorism in Peru. Furthermore, the students highlighted that the opportunity to engage in simulations of pivotal historical events enabled them to gain a deeper comprehension of the underlying causes and consequences of terrorism in the country.

Consequently, the virtual reality web application was well received and highly valued by students when utilized as an adjunct to traditional instruction, thereby substantiating its efficacy as an educational adjunct in historical subjects. The results indicated that 93% of respondents rated the VR web application as highly user-friendly, and 100% of respondents considered VR to be an extremely useful tool for learning about terrorism in Peru.

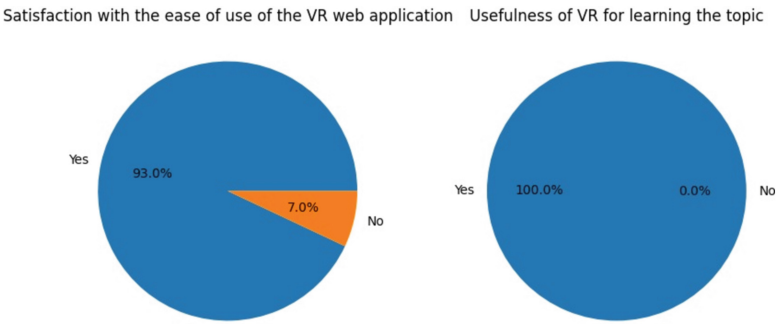

Fig. 7. Pie charts illustrate the degree of satisfaction with regard to the ease of use and usability of the implementation of the virtual reality application.

The students expressed that they found the use of VR to be highly beneficial for learning the subject.

8 Conclusions

The general objective of developing a virtual reality web application to enhance the teaching of history to high school students in Lima, Peru, was successfully achieved. The initial motivation for the lack of standardized methodologies to design effective VR experiences in education was overcome by the EduVR proposal, which, by using the FrameVR platform, integrates a client-server architecture with a solid backend. This represents a valuable contribution as a virtual reality solution specifically focused on educational purposes.

The novelty of the EduVR method lies in its integration of advanced techniques such as interactive simulation and 360° images, which collectively offer an immersive and participatory experience that makes VR accessible and user-friendly for students and teachers. The case study demonstrated that the VR web application, when integrated with traditional education, significantly enhances students' comprehension and retention of historical knowledge. Students who utilized the VR application exhibited a 4-point improvement on their exam scores, whereas those who did not utilize the application demonstrated only a 1-point improvement.

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We would also like to thank the Emmanuel School in Villa El Salvador for facilitating the development of the case study, allowing the implementation of the virtual reality web application and the evaluation with their students.

Finally, we acknowledge the valuable contribution of the participating teachers and students, who dedicated their time to the tests, answering surveys and interviews, and provided very useful suggestions that allowed us to improve the web application and the educational experience.

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Automated System for Improving Audit Data Processing Through DAMA-DMBOK Best Practices and Low-Code

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Abstract. In the context of financial auditing, the efficient retrieval of accurate data, minimization of reprocessing efforts, mitigation of inherent risks in data processing, and improvement of information quality represent crucial objectives. In this regard, we present an automated system designed to optimize data processing in auditing. This system provides an automated assessment of the six data quality dimensions according to the DAMA model: completeness, reasonability, accuracy, uniqueness, validity, and consistency. This process is essential to determine whether data sources meet the necessary standards for use in various analytical processes. The tool was validated in the Wholesale Banking Management of Banco de Crédito del Perú, where it successfully analyzed 100% of data sources in the commercial credit audit, reducing the processing time of each source by 10 times. These results confirm that our software significantly contributes to improving data processing in the field of financial auditing. This system has proven to be effective and reliable in enhancing the overall efficiency and accuracy of financial audits.

Keywords: Financial auditing · Data processing · Low-code · Automated system

1 Introduction

Data processing plays a fundamental role in the modern digital landscape, as information is constantly generated and flows at a rapid pace, and decision-making relies on this flow [8]. The significance of data processing lies in its ability to transform raw information into valuable knowledge, enabling organizations to optimize their operations and achieve their objectives efficiently [3]. The advent of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) has further escalated the volume and velocity of data being generated, emphasizing the critical need for efficient data processing mechanisms [14].

However, data processing is not without challenges [12]. The causes and consequences related to the completeness, accuracy, and integrity of data can have a significant impact on the quality of decision-making [11]. The lack of complete and accurate data can lead to incorrect decisions during predictions and analyses, generating distrust in

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the results [6]. This, in turn, can have a negative effect on the reputation and profitability of an organization [9].

As the amount of data that organizations manage continues to increase exponentially, the need for effective tools to enhance data processing becomes even more pressing [2]. Implementing these tools can be a challenge, as it requires technical resources, training, and a deep understanding of the organization's needs [8]. The process of improving data processing is complex and often involves changes in technological infrastructure, data management, and business processes [5].

In this context, two emerging approaches, "Low-Code" and "DAMA-DMBOK" (Data Management Body of Knowledge), are gaining relevance as promising solutions to enhance data processing [13, 15]. "Low-code" simplifies the development of applications and data processing systems, allowing organizations to expedite the implementation of solutions efficiently [1, 4]. On the other hand, "DAMA-DMBOK" provides a robust framework and best practices for data management, helping to ensure the quality and integrity of processed data [7, 10]. These methodologies offer a structured approach to tackle the inherent complexities of data processing, providing organizations with the tools needed to address the challenges posed by the ever-increasing volume and variety of data [15].

We will delve deeper into how "Low-Code" and "DAMA-DMBOK" can be used as effective tools to enhance data processing and address challenges associated with data completeness, accuracy, and integrity in an ever-evolving business environment. This research aims to explore the synergies between these two approaches and assess their potential impact on improving data processing capabilities and decision-making quality in organizations.

2 Related Work

During this research, various systems designed to enhance data processing were studied, each with specific approaches. Among them are notable: the use of Deep Learning technology to strengthen the detection and resolution of vulnerabilities [8], the application of blockchain to verify the integrity and security of data in digital contracts [14], probabilistic-statistical models for identifying patterns and trends in financial data [9], and systems oriented towards real-time data processing using IoT and Blockchain in financial transactions [3].

In recent years, Deep Learning has gained significant attention for its ability to analyze and process vast amounts of data, particularly in the domain of cybersecurity. Research by Smith et al. [8] demonstrated the effectiveness of Deep Learning in identifying and resolving vulnerabilities, showcasing its potential in enhancing data security. Furthermore, blockchain technology has been leveraged to ensure the integrity and security of data in digital contracts. The decentralized nature of blockchain provides a robust framework for data verification and validation [14].

Additionally, probabilistic-statistical models have been extensively used to identify intricate patterns and trends in financial data. These models offer valuable insights into the behavior and dynamics of financial markets, aiding in predictive analysis and decision-making [9].

Moreover, the integration of IoT (Internet of Things) with Blockchain has paved the way for real-time data processing in financial transactions. This integration enhances the efficiency and security of transactions by leveraging the decentralized and transparent nature of blockchain technology [3].

Despite the relevance of these studies, it is determined that they are not directly applicable to our problem. The reason is that they focus on pattern detection, lacking extrapolation to the use of structured data and non-real-time auditing. In the field of auditing, it is essential to subject data to various integrity and quality filters, an aspect not addressed in the reviewed research, as they focus on other analyses and applications. They are proposals more oriented towards data collection and its respective validation. Likewise, these technologies imply a high cost, as well as the need for experts with experience in the field and technology. For our case study, there is no budget for this type of project, as it is a small business unit within a larger area that has little to do with technologies.

3 Method

In our architecture, we use Power Platform, that is a Microsoft product of a suite of SaaS apps based in Low Code, provided to non-specialists (or specialists) to create high quality end products with way less effort, expertise and training. We use Power Apps, a powerful tool that allow us to create a Web Application. A web application usually needs to be hosted in the intranet or internet and that hosting obviously is not free and so the proper maintenance and security. Microsoft provided us and we benefited from all that powerful infrastructure, to obtain a great performance, strong security and high availability. Microsoft interconnects their products, especially the suite of MS Platform, so to exploit this we use Power Platform, that give us powerful tools to automate our workflow.

At the core of the data processing architecture, the person in charge of assessing information quality accesses it through their business laptop. In this context, hardware is irrelevant as the resources used by the application reside in the Microsoft 365 cloud. The application is hosted in the resource group provided by Azure along with the license, and access requires authentication through Microsoft Authenticator by entering credentials (business email and authenticator token). This authentication is verified through Azure Active Directory and allows the connection trough the Azure Gatheway.

Once the user has logged into their company's 365 environment and, in particular, into the Power Apps application, they are granted access to two fundamental components: the source management interface and the historical tracking of sources. The integration of Power Apps with the 365 environment allows easy data visualization limitation by filtering user profiles. The use of the application is not anonymous, allowing user identification through their business credentials. The source management interface empowers the user to control and efficiently manage the sources of information they will analyze.

In this context, the user can create a source request using a pre-designed template, register it, and trigger a flow with Power Automate that facilitates communication with the source manager through emails with Outlook. The request includes crucial information (date, query, manager's name, superior, among others) to ensure clarity and avoid

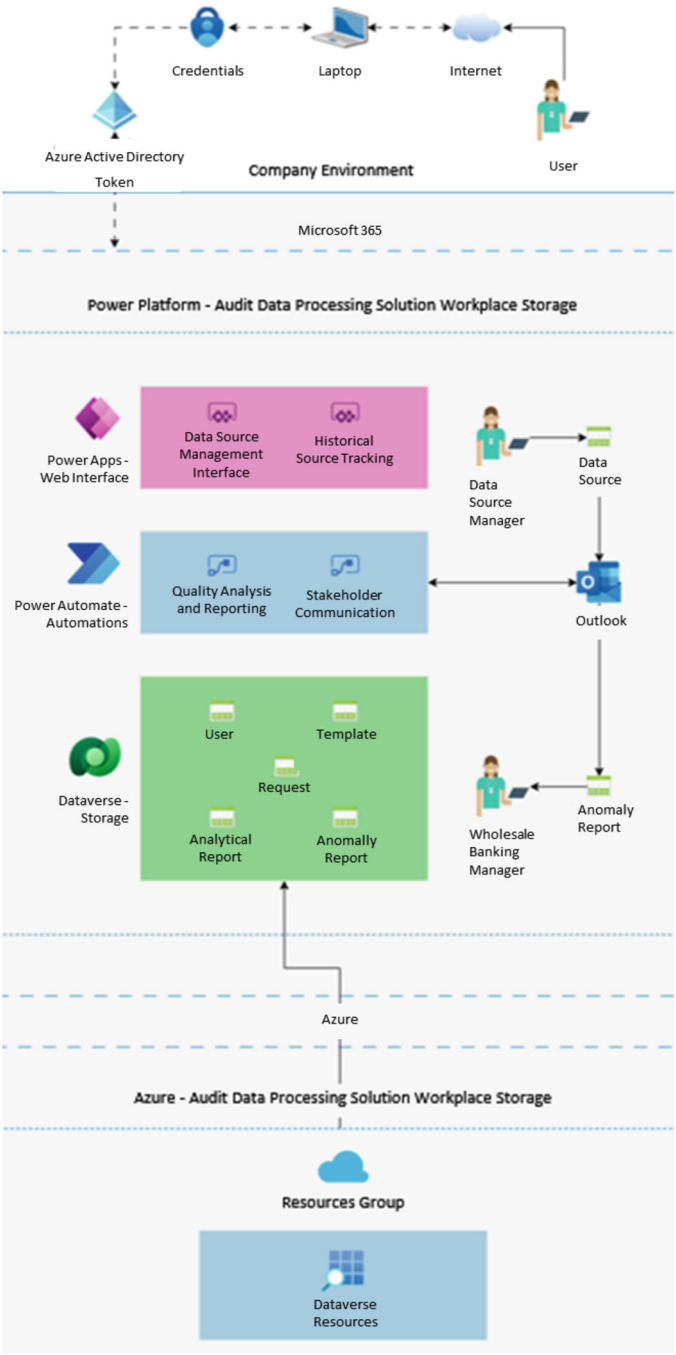

Fig. 1. Physical Architecture of the Automated Data Processing System.

ambiguities. The flow automatically determines the action plan and notifies the user of the result. In case of no response, periodic follow-up is carried out; if there is a response, the attachment is captured and stored in the Dataverse cloud data engine, located in the paid business resource group.

Once the sources for quality analysis are obtained, the flow is automatically activated on the scheduled date in the request, generating a report covering the 6 DAMA-DMBOK quality dimensions: completeness, reasonability, accuracy, uniqueness, validity, and consistency. This report is stored and notified to stakeholders: management and the user. This stage is essential as flows operate as cloud computing, meaning that, being horizontal scaling Microsoft provide us several nodes to distribute the load so they do not need to wait for one flow to finish before another begins. Thus, even with 10 simultaneous data analyses, the solution ensures consistent performance.

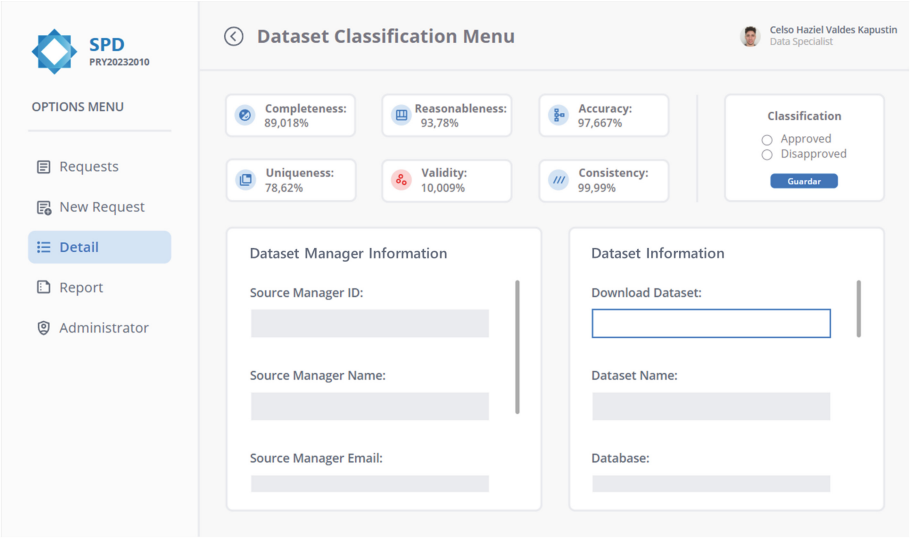

Fig. 2. Dataset Classification of the Automated Data Processing System.

The results of this analysis serve as input for the historical tracking of sources, providing a retrospective view of the evolution of information sources over time. This layer easily integrates with Dataverse, showing previous results for each source for comparison. If the dataset approved after analysis meets requirements, it must be supplemented with exploratory descriptive analysis (EDA) by the user, who then attaches this analysis to the application, turning it into a centralized tool for source quality control.

Finally, in Dataverse storage, relevant information will be saved in entities such as users, requests, anomaly reports, analytical reports, and templates. These tables are relationally integrated through primary keys and cardinality. To better understand the physical architecture of the proposed system, please refer to Fig. 1.

To start, a web interface was developed, resulting in a CRUD application that centralizes all agents, as referenced in Fig. 2. Subsequently, for the back office, flows were

developed using Power Automate: ReportLoading, DatasetLoading, and QualityCalculation, as shown in Fig. 3. To support data quality calculation, a script was developed using Office Script.

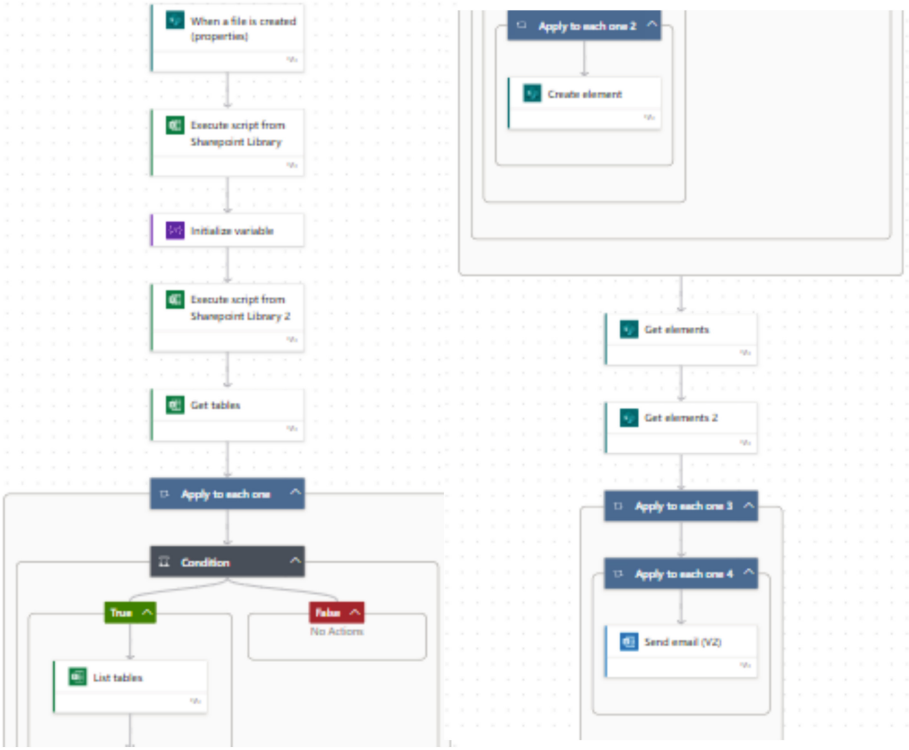

Fig. 3. Data Quality Flow of the Automated Data Processing System.

4 Validation

In the validation process, a comprehensive comparison was meticulously conducted between the developed system and the traditional method previously employed for data processing and analysis. The data processing flow in Wholesale Banking starts with the data auditor identifying data sources, verifying access, and determining the scope. If the data is not on the server, it is uploaded to the sandbox in the DWH. Stored procedures are then executed to check the six DAMA quality dimensions, resulting in a detailed report and a summary. The data's integrity is validated, and if it is not integral, it is discarded, and validation reports are sent. If the data is integral, further analysis is conducted with Python, normalizing and exploring the data. Results are sent to the Product Owner, the head of the data team, and the wholesale team manager. Subsequently, sources are loaded into the project data manager's development environment, and the Product Owner orders

project execution. If errors occur, the data auditor performs maintenance and reports the issue, repeating execution until errors cease. Finally, results are communicated to the Product Owner, who orders data visualization, and the analysis is presented for the Product Owner and manager to extract conclusions, completing the process. The main errors include a lack of prior data normalization and transformation, causing interruptions if there are differences in data types. There is also a lack of preliminary source preparation, leading to continuous maintenance. Additionally, poor integration of solutions complicates massive data uploads considering there's only one data specialist for each business team, especially without frameworks or data governance guidelines and without bridge technologies like pipelines, resulting in additional costs and potential upload errors.

The findings of this rigorous evaluation revealed a marked contrast in processing times between both approaches, underscoring the remarkable efficiency of the proposed data management system. The system demonstrated notable agility by completing the task in an average time of 4 min, even when tasked with processing a considerable volume of data ranging between 10 and 20 thousand records. In stark contrast, the historically used traditional method necessitated significantly more time to complete the same task, with estimated effective processing times ranging between 1 and 2 h. This substantial discrepancy clearly highlighted a significant improvement in data processing efficiency with the implementation of the developed system.

It is crucial to highlight that the advantage of the developed system lies not only in the speed of processing but also in its sophisticated capability to conduct multiple analyses simultaneously through the utilization of cloud computing. This groundbreaking capability allowed for the simultaneous analysis of all data sources in a single working day, thereby optimizing both time and resources to a remarkable extent. The system's autonomy, which operates without relying directly on the intervention of a data analyst, further contributed to the optimization of time and resources, marking a significant advancement in automated data processing and analysis methodologies.

Moreover, the system's adaptability and scalability were meticulously assessed, revealing its exceptional ability to handle increasing data volumes without compromising on performance or efficiency. The system's meticulously designed architecture is specifically engineered to efficiently manage larger datasets by leveraging the distributed computing resources available in the cloud. This inherent scalability ensures that the system can seamlessly adapt to the growing demands of data processing in contemporary research environments, marking a significant advancement in data management and analysis capabilities.

In contrast, the traditional method, which relied heavily on the manual intervention of a data analyst, was inherently limited by the available human capacity. The delay in quality processing reached an alarming 16 working days, primarily due to the overwhelming workload of the data auditor, creating a significant bottleneck in the information processing flow. It is important to note that datasets with similar extensions, for example, 18–25 columns, were meticulously selected for comparison, and it was observed that as the volume of data increased, the increase in the system's effective time to perform quality analysis was considerable. However, this difference is effectively offset when comparing the total time spent analyzing all sources using the developed system compared to the traditional method, which, while it may take less time with higher data volumes, is also

subject to the auditor's availability and technical capacity, highlighting the limitations of manual data processing methodologies.

Furthermore, the system's reliability and accuracy were rigorously evaluated, demonstrating consistent performance in data analysis and significantly reducing the margin of error compared to the traditional method. The implementation of automated processes in the system ensures a more standardized and reliable analysis, minimizing human error and variability to a remarkable extent. This enhanced reliability and accuracy represent a significant advancement in data analysis methodologies, contributing to the overall credibility and trustworthiness of the data analysis results produced by the developed system.

In Fig. 4, which is presented in the subsequent section, the times explained in the previous paragraphs can be graphically visualized, providing a clear and comprehensive comparison between the developed system and the traditional method in terms of processing efficiency, scalability, and reliability. These is the validation of the data quality evaluation presented in Fig. 3.

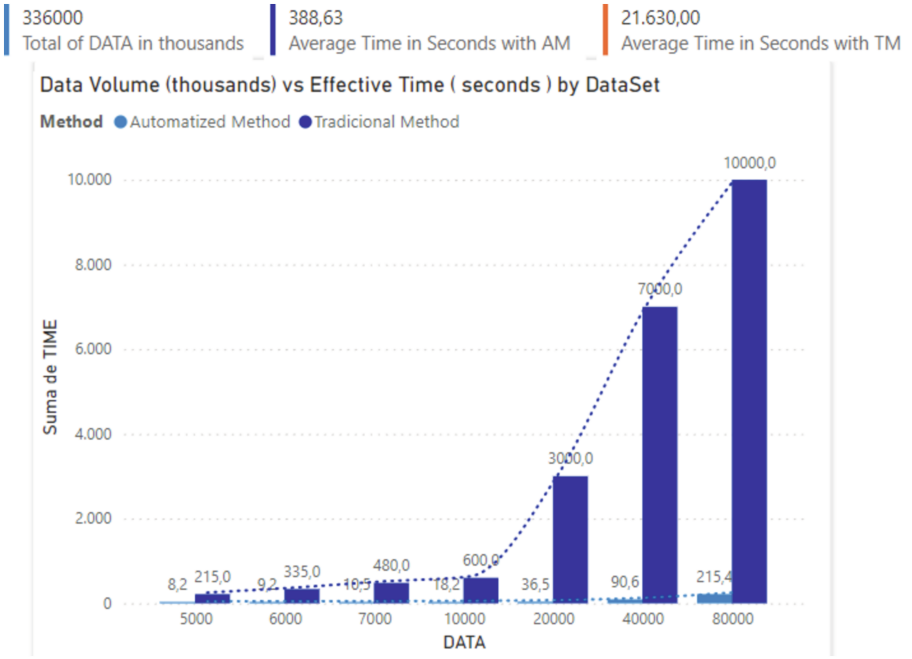

Fig. 4. Results obtained with the Automated Data Processing System.

5 Conclusions and Recommendations

5.1 Conclusions

In conclusion, the integration of a low-code approach in data processing has demonstrated substantial efficacy in addressing the multifaceted requirements of information quality analysis within financial auditing. This innovative and groundbreaking approach has not only streamlined the intricate and complex processes involved in data analysis but has also significantly enhanced the accuracy, reliability, and efficiency of the information derived. The system's architecture, characterized by its high level of maturity and sophistication, exhibits an advanced framework that centralizes and streamlines user tasks, thereby optimizing the time required for data processing and providing a conducive environment for continuous monitoring, improvement, and innovation. Developed with the primary objective of maximizing efficiency while utilizing minimal resources, the system showcases remarkable adaptability and scalability. This adaptability not only lays a robust foundation for potential enhancements and optimizations but also emphasizes the system's potential for seamless integration with emerging technologies and advanced tools available in the market. It is this inherent flexibility, adaptability, and forward-thinking approach that ensures the system's capacity to evolve, adapt, and cater to the evolving demands, challenges, and technological advancements in the ever-changing and dynamic business landscape.

Despite the system's current limitations in managing extensive data volumes, its value as a practical example and testament to the benefits of data processing initiatives remains undeniable and invaluable. The effective utilization of distributed computing capabilities offered by cloud tools accentuates the system's efficiency, marking a significant advancement in data analysis methodologies and presenting a solution that not only enhances the data analysis process but also serves as a benchmark for future advancements, innovations, and best practices in analogous business environments.

5.2 Recommendations

Considering the system's current limitations in handling extensive data volumes, the integration of advanced technologies capable of efficiently managing larger data volumes without compromising on efficiency is strongly advised and recommended. This integration would involve leveraging cutting-edge technologies, methodologies, and best practices to enhance the system's data processing capabilities, performance, and scalability. Furthermore, ongoing and continuous training sessions for users and data analysts are imperative and essential to ensure optimal utilization of the system's features, functionalities, and capabilities and to keep the team, organization, and stakeholders abreast of the latest technological advancements, trends, and developments. These training sessions would serve as a platform for continuous learning, development, innovation, and excellence, fostering a culture of continuous improvement, innovation, and excellence within the organization, thereby enhancing the organization's competitive advantage, market position, and overall success.

Moreover, it is essential to consider and prioritize the integration of sophisticated and advanced analytics like machine learning models, for example clustering models like

DBSCAN or OPTICS, to amplify the system's predictive capabilities, performance, and value proposition. These advanced analytics tools would facilitate more comprehensive, detailed, and insightful data analysis, providing deeper insights, valuable information, and aiding in making precise, informed, and strategic decisions that drive organizational success, growth, and profitability. A thorough and comprehensive assessment of the system's scalability, capabilities, and performance is also recommended and advised to understand its potential, capacity, and ability to manage, process, and analyze increasing data volumes, complexities, and challenges in the future. This proactive and forward-thinking approach will enable the organization to plan, strategize, and implement necessary upgrades, modifications, and enhancements in a timely, efficient, and effective manner, ensuring seamless operations, optimal performance, and sustainable success.

Additionally, implementing a structured, systematic, and comprehensive feedback mechanism, process, and system with the users, stakeholders, and relevant parties is crucial, essential, and vital to garner, collect, and obtain valuable insights, feedback, and information into the system's performance, capabilities, functionalities, and user experience and to identify, address, and rectify areas, aspects, and opportunities for enhancement, improvement, and optimization. This feedback-driven approach, process, and system will facilitate continuous, ongoing, and iterative refinement, improvement, and enhancement of the system based on real-world usage, feedback, and insights, ensuring that the system remains aligned, compatible, and consistent with the organization's objectives, requirements, goals, strategies, and vision.

Lastly, conducting a comprehensive, thorough, and detailed cost-benefit analysis, evaluation, and assessment to evaluate, measure, and assess the return on investment (ROI) of the implemented system will provide valuable, insightful, and actionable insights, information, and data into the system's economic viability, financial performance, and its contribution to the organization's profitability, success, and sustainability. This comprehensive and detailed analysis will serve as a critical, essential, and invaluable tool, resource, and asset for decision-making, strategic planning, and management, helping the organization, stakeholders, and decision-makers to assess, evaluate, measure, and understand the tangible and intangible benefits, advantages, and value derived from the system and to identify, explore, and capitalize on opportunities, potential, and possibilities for further optimization, enhancement, improvement, and innovation to drive organizational success, growth, profitability, and sustainability in the ever-changing and dynamic business landscape.

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Empowering Environmental Stewardship in Panama: A Mobile Application for Monitoring Greenhouse Gas Emissions

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Abstract. Currently, the global warming problem affects every country worldwide, and Panama, as a signatory of the Paris Agreement, is no exception. In response to this urgent issue, this paper presents an innovative mobile application designed to monitor and control greenhouse gas emissions in Panamanian households, aiming to increase awareness and promote actionable change. The application development process involved a thorough requirements analysis, leading to its architectural design and subsequent development and validation. Based on the evaluation results, providing users with a clear visualization of their emissions encourages both individual and collective actions to reduce their carbon footprint, aligning with Panama's commitment to the Paris Agreement. While addressing local concerns, this effort contributes significantly to the global fight against climate change, showcasing the power of technological solutions in ecological conservation. This study's main contributions include the development of a user-centric mobile application for emission monitoring, an in-depth analysis of user engagement with environmental data, and a demonstration of the practical impact of technology-driven initiatives in fostering environmental stewardship in Panama. The work presented in this paper intersects theoretical research and practical technological application, offering a viable solution to a pressing global issue.

Keywords: Global warming · Climate change · Greenhouse gas emissions · Mobile application

1 Introduction

The United Nations Organization defines global warming as a phenomenon that causes an increase in the Earth's average temperature and the water covering it [1]. Some of its main causes are greenhouse gases, which accumulate within the atmosphere and absorb the sun's energy, causing an increase in the planet's global temperature [2]. The main greenhouse gases that cause global warming are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and they are generated mainly by anthropogenic sources such as combustion of fossil fuels, industrial processes, and waste [3].

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Global warming leads to more frequent heat waves, increased rainfall, and extreme climate events, negatively impacting human communities and ecosystems [4]. According to NASA, Earth's average surface temperature in 2023 was the warmest since record-keeping began in 1880, and the ten most recent years are the warmest years on record [5]. Therefore, it can be stated that it is a real problem that affects our planet, and its consequences and repercussions are increasingly noticeable daily.

Given that greenhouse gases are generated mainly by human activities, solutions to help people worldwide have control over the emissions of these gases are necessary. Current technological advances make it possible to propose and develop these solutions, allowing addressing global warming from different perspectives and levels.

In this sense, this paper proposes a mobile application that allows users to keep track of the greenhouse gas emissions they generate as part of their daily home activities. The application aims to raise awareness among the Panamanian population about the importance of reducing greenhouse gas emissions in daily activities. By doing so, it seeks to contribute to controlling and reducing these emissions in Panama to mitigate the impact of climate change.

This paper is organized as follows: Sect. 2 covers the current state of the global warming issue in Panama. Section 3 focuses on the design and implementation of the mobile application. Section 4 presents the evaluation and results. Finally, Sect. 5 concludes the paper.

2 Current State of the Global Warming Issue in Panama

Panama is a country highly vulnerable to the effects of global warming and climate change. The temperature in this country has reflected variability in re- cent years, with an increase of 1 to 2 °C in different regions of its territory. This increase has highlighted growing vulnerability in the country's key economic sectors, as well as in natural resources and vital ecosystems related to the availability of water resources, agricultural activities, human health, and the development of marine and coastal areas and cities [6].

In attendance to this situation, the inauguration of Panama's National Green- house Gas Inventory System underscores the nation's dedication to tackling climate change and advancing toward sustainable development. This initiative marks a pivotal step for Panama, as such inventories are vital for informing pol- icy and strategy decisions concerning climate change mitigation and adaptation efforts [7].

In September 2021, Panama updated its Nationally Determined Contribution (NDC) to align with the Paris Agreement. The NDC outlines more rigorous targets for curtailing greenhouse gas emissions and details precise strategies to meet these objectives [8].

Moreover, Panama's enactment of legislation in May 2021 aimed at the conservation of wetlands signifies another key effort to address climate challenges.

This legislation focuses on the preservation and sustainable management of wetlands, recognizing their critical role in climate change mitigation and adaptation and their importance in supporting a diverse range of flora and fauna [9].

In the context of climate change and Panama's efforts to combat it, a notable announcement was made by President Laurentino Cortizo in November 2020. He signed the Declaration of Carbon-Negative Countries alongside representatives from Suriname

and Bhutan. This agreement positions these nations as the only ones worldwide that absorb more greenhouse gases than they emit from human activities. The goal of the Declaration is to renew the commitment to fight against climate change and to highlight the need to increase the global capacity for adaptation to its adverse effects, as well as to enhance financial flows to a level that supports low-emission, climate-resilient, and carbon-neutral development by the year 2050 [10].

2.1 Panama's Canal

The Panama Canal, the country's primary revenue source, has been impacted by water scarcity in its reserves due to high temperatures and droughts during climatic periods, forcing some ships to reduce their cargo to avoid groundings. Moreover, intense storms have threatened the Canal's dams and locks. The main issue is the lack of rainfall required to operate the 50-mile waterway, through which 4 % of global trade passes. According to the Panama Canal Authority, four of the past seven years have been among the driest since 1950. To address this challenge, Canal authorities are devising a $2 billion plan to construct infrastructure to manage and preserve freshwater reserves, equivalent to the Canal's annual contributions to the Panamanian government [11].

By the end of June 2021, Panama Canal representatives announced they would select from 30 potential solutions to tackle water scarcity, with proposals expected to be tendered within two years. The projects, aimed to be completed by 2028, are anticipated to integrate the construction of new dams and reservoirs, the use of treated wastewater, and the exploration of alternative freshwater sources, such as diverting flows from other rivers. The possibility of pumping desalinated seawater has also been considered [12].

These measures seek to address the consequences of global warming in this country; however, preventive measures that involve all citizens are also required.

3 Mobile Application Design and Implementation

This section describes the analysis, design, and implementation of the proposed mobile application. It highlights the set of software requirements that define the application's scope, describes the application's architecture, presents the user interface design, and describes the development decisions.

3.1 Software Requirements

The requirements-gathering stage is one of the most critical phases in software development because it defines the functionalities and behavior the software will possess once developed.

The following software requirements define the scope of the proposed mobile application:

1. Dashboard Display Requirement
   - Objective: Enable general users to view consumption summaries of their households.

- Functionality: Upon user login, the system shall automatically navigate to the main screen, displaying a dashboard with graphical representations of recorded consumption data.

2. Household Emission Registration Requirement
   - Objective: Allow home administrators to add new emission entries to their households.
   - Functionality: The system shall provide an interface where users can select an option to add a new emission, categorize it, and input corresponding data that the system will validate and store.
3. Add Household Requirement
   - Objective: Allow users to add a new household to their account.
   - Functionality: Users shall be able to fill out a form to add a household, after which the system will create and display the new household on the main screen.
4. User Registration Requirement
   - Objective: Facilitate user registration within the application.
   - Functionality: The application shall offer a registration form where new users can input their details. Upon validation of these details, the system shall register the user and log them in automatically.
5. Household Management Requirement
   - Objective: Enable home administrators to modify household data and user roles.
   - Functionality: Users shall be able to select an'Edit Household' option, update the information, and upon confirmation, the system updates and displays the modified details.
6. Login Requirement
   - Objective: Allow users to log into the application.
   - Functionality: Users shall enter their credentials, and upon validation, the system grants access to the application's functionalities by redirecting to the main screen.
7. Logout Requirement
   - Objective: Provide a secure method for users to log out of the application.
   - Functionality: Upon selecting the'Logout' option, the system shall terminate the session and redirect the user to the login interface.
8. View Registered Households Requirement
   - Objective: Enable users to view all linked households.
   - Functionality: Once logged in, users selecting the'Households' option shall be shown a list of all registered households they are associated with.
9. Edit Profile Requirement
   - Objective: Allow users to update their personal profile information.

- Functionality: Users can select'Edit Profile' and modify their information, and upon saving, the system confirms the updates and redirects to the profile page.

10. Consumption Reminder Requirement
    - Objective: Remind users to register their consumption activities.
    - Functionality: The system shall send notifications to users who have not logged consumption in the last seven days.
11. Emission Reduction Suggestion Requirement
    - Objective: Provide users with suggestions for reducing their emissions.
    - Functionality: Upon user login, the system displays customized suggestions based on the household's consumption patterns over a specified period.
12. List Emissions by Household Requirement
    - Objective: Allow users to view emissions specific to a selected household.
    - Functionality: Users can select a household from their list, and the system will display all emissions related to that household.
13. List Emissions by User Requirement
    - Objective: Enable users to view their personal emissions history.
    - Functionality: Upon selecting the'Profile' option, the system displays the user's emission history, including graphs of emissions by household and category.

3.2 Architecture

Some views of the 4+1 view model was applied to define the architecture of the proposed mobile application.

Figure 1 shows the development view of the architecture, which focuses on the application's internal structure and how the software components are organized to achieve the functional objectives.

Moreover, Fig. 2 shows the logical view of the architecture, which describes the application's functionalities to users and serves as a conceptual framework to define the interrelations of diverse entities for the application.

The key entities of this logical view are described as follows:

- UserSettings: Captures individual user preferences and settings, linked by user ID to the Usuario entity.
- Languages: Enumerates available languages within the application with identifiers and descriptions.
- MeasurementUnits: Catalogs various units of measure with unique identifiers and descriptive details.
- EmissionType and Emission: Define emission types and track individual emission instances, including relationships indicating the emission type.
- User: Central to the application, this entity details user information, supporting functions like registration and login.
- Gender: Offers a user gender classification system.

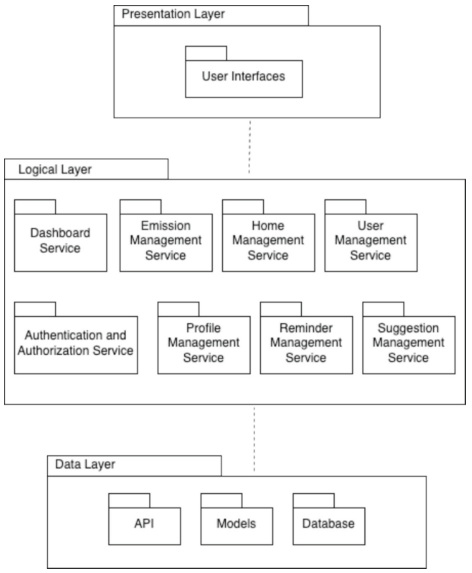

Fig. 1. Development view diagram for the proposed mobile application

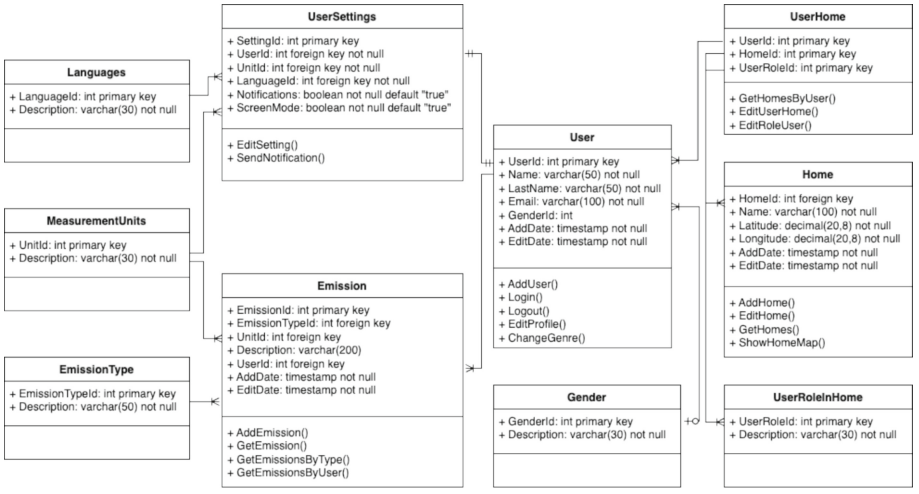

Fig. 2. Logical view diagram for the proposed mobile application

– UserHome: Acts as a junction table linking users to households, suggesting multiple homes per user and vice versa.
– Home: Details households within the application, providing management functionalities.
– UserRoleInHome: Delineates user roles within a household to facilitate permission settings.

3.3 User Interfaces Design

Low-fidelity and high-fidelity prototypes were created to design the user inter- faces for the mobile application. Balsamiq Mockups were used to design low- fidelity prototypes using wireframes. These prototypes served as preliminary vi sualizations that facilitated initial evaluations of the application user interfaces.

With the feedback and insights gained from the low-fidelity prototype evaluations, high-fidelity prototypes were implemented. A basic design system (including elements such as colors and fonts) was created to ensure a consistent look and feel across all the app interfaces and standardize all the UI elements and components. After creating the design system and deciding on high-level design choices, the Figma software was used to develop a high-fidelity prototype.

Figures 3, 4, and 5 show some high-fidelity prototypes designed for the proposed mobile application.

The prototype includes several user interfaces, each designed to represent different functionalities of the intended final product.

3.4 Frontend and Backend Development

The development of the mobile application's frontend was implemented using Flutter, a modern framework that enables the creation of native user interfaces across multiple platforms from a single codebase. Flutter allows compiling into native code, enhancing performance and significantly enriching the user experience. Its widgets were crucial in crafting responsive and interactive user interfaces adaptable to various device screens. Additionally, since the application was developed with Flutter, Dart was used as the frontend programming language.

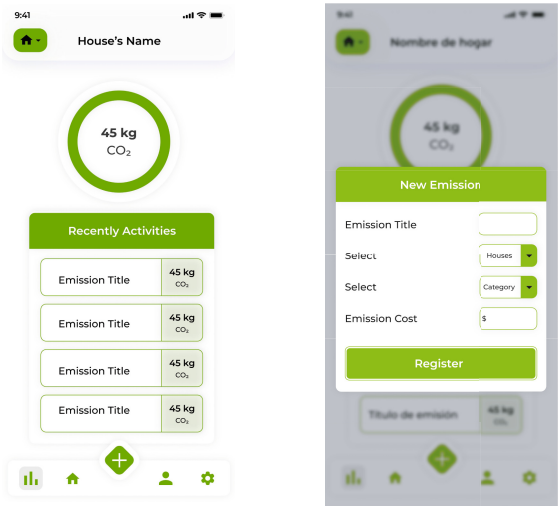

Fig. 3. High-fidelity prototype for the mobile application homepage user interface where (a) a summary of recent emissions per household is shown and (b) a new emission can be added.

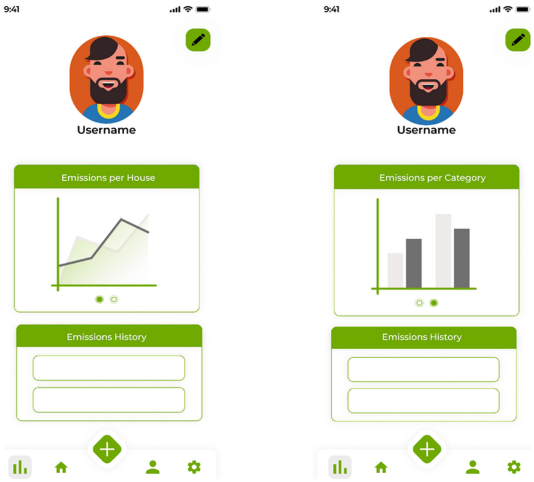

Fig. 4. High-fidelity prototypes for the user interfaces that show the emissions generated by a user.

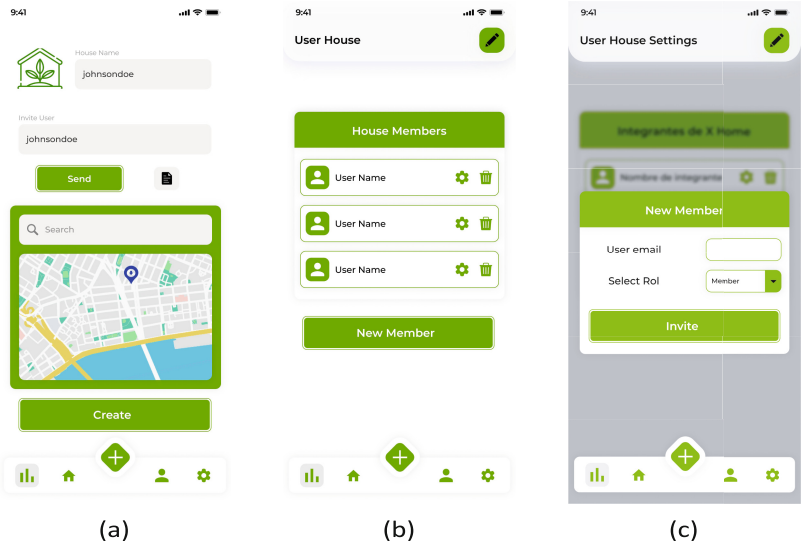

Fig. 5. High-fidelity prototype for the mobile application user interfaces where (a) a new house can be added, (b) the members of a house are shown, and (c) a new member can be added to a house.

For backend services, Firebase was chosen. This platform, developed by Google, provides a suite of tools for database management, user authentication, and backend configurations without the need to manage on-premise servers. The integration between Firebase and Flutter facilitated seamless synchronization and data management between the application's frontend and backend.

4 Evaluation and Results

This section focuses on evaluating the proposed mobile application. It includes the evaluation design based on different scenarios and the evaluation results.

4.1 Evaluation Design

An evaluation plan using scenario-based testing was designed to assess the mobile application's functionality and usability. This approach simulated real-life situations to evaluate how well the application performed in terms of functionality and user experience. Table 1 shows the description of the proposed scenarios.

The evaluation involved 20 participants, representing a diverse cross-section of the Panamanian population, including different age groups, technical proficiency levels, and backgrounds. Participants completed tasks related to the scenarios. Any issues encountered were recorded, and feedback was gathered.

4.2 Detailed Evaluation Methodology

The evaluation of the proposed mobile application was carried out using a comprehensive methodology, carefully designed to assess the application's usability and effectiveness in promoting environmental awareness and action.

Participant Selection. Participants were selected to represent a diverse demo- graphic profile of the Panamanian population. Criteria for selection included age, technological proficiency, and geographical location, ensuring a representative sample of potential users. This diversity allows us to understand the application's usability across different user groups, thereby providing more generalized and robust findings.

Task Descriptions. Participants were asked to complete a series of predefined tasks that simulate real-life scenarios of application usage. These tasks were designed to test all core functionalities of the application, including:

- Account registration and user login.
- Navigation through the application to access different features.
- Entry and tracking of household emissions.
- Utilization of tools provided by the application for recommending emission reduction strategies.
- Interpretation of data visualizations displayed on the application's dashboard.

Metrics. The performance of participants in completing the tasks was evaluated using the following metrics:

- **Task Completion Rate (%):** The percentage of tasks completed successfully by the participants without external assistance.
- **Error Rate (%):** Frequency of errors made by participants while interacting with the application.

Table 1. Description of the proposed scenarios for user evaluation.

Scenario	Task	Success Criteria
User registration	Participants will open the app and complete the registration form with their personal details.	Participants should be able to register without assistance and be automatically logged
Login	Participants will enter their credentials and log into the application.	Participants should be able to log in and be redirected to the main screen without errors.
Dashboard display	After logging in, participants will navigate to the dashboard to view graphical representations of their household's recorded consumption data.	Participants should be able to access the dashboard easily and interpret the data without confusion.
Add household	Participants will access the "add household" feature, fill out the form to add a new household, and verify that it appears on the main screen.	Participants should be able to add a household and see it listed on the main screen without encountering issues.
Household emission registration	Participants will navigate to the emission registration feature, select a household, and add a new emission entry with the required data.	Participants should be able to add an emission entry accurately, and the system should validate and store the information correctly.
List emissions by household	Participants will select a household from their list and view all emissions related to it.	Participants should be able to select a household and see all relevant emissions data easily.
Emission reduction suggestions	After logging in, participants will review the customized suggestions for reducing emissions based on their household's consumption patterns.	Participants should understand and find the suggestions useful and applicable to their household activities.
Consumption reminder notifications	Participants will check the notifications received for logging consumption and follow the prompts to log an activity.	Participants should find the reminders helpful and be able to log activities without difficulty.
Edit household information	Participants will select a household to edit, update the information, and confirm the changes.	Participants should be able to edit and save changes to household data, which should then be correctly updated and displayed.
View personal emissions history	Participants will select the "Profile" option and review their personal emissions history, including graphical data.	Participants should be able to navigate to their profile and understand their emissions history easily.
Edit user profile	Participants will navigate to "Edit Profile," update their information, and save the changes.	Participants should be able to edit their profile details and see the updated information reflected immediately.
Logout	Participants will select the "Logout" option to end their session and return to the login interface.	Participants should be able to log out securely and be redirected to the login screen without issues.

- **Ease of Use (%):** Assessed through direct feedback from participants regarding their experience using the application, focusing on its intuitiveness and user-friendliness.
- **User Satisfaction (%):** Measured through post-interaction surveys that gauge overall satisfaction with various aspects of the application, including its interface, functionality, and the relevance of the content provided.

These metrics provide a thorough understanding of the application's performance from the user's perspective and highlight areas where further improvements could be made to enhance user experience and effectiveness.

4.3 Results

The mobile application's usability and functionality evaluation assessed its core features' ease of use and performance.

Table 2 shows the obtained results, including metrics such as task completion rate, error rate, ease of use of interfaces, and user satisfaction.

Table 2. Description of the proposed scenarios for user evaluation

Scenario	Task completion rate (%)	Error rate (%)	Ease of use (%)	User satisfaction (%)
User registration	95%	5%	100%	100%
Login	90%	5%	85%	80%
Dashboard display	95%	4%	90%	88%
Add household	80%	15%	75%	70%
Household emission registration	78%	18%	70%	72%
List of emissions by household	88%	10%	82%	80%
Consumption reminder notifications	100%	0%	100%	90%
Edit household information	75%	20%	68%	65%
View personal emissions history	92%	6%	88%	85%
Edit user profile	84%	10%	80%	78%
Logout	94%	3%	92%	90%

The results depicted in Table 2 report a detailed performance evaluation of user interactions with various mobile application features. Overall, task completion rates

were high, reflecting a robust system design, with particularly excellent performance noted in the 'Dashboard display' (95%) and 'Logout' (94%) tasks. Conversely, the error rate was significantly higher than what was expected. For instance, the 'Edit household information' task displays a notably higher error rate (20%) and lower ease of use (68%), pinpointing a critical area for improvement.

Participants reported that the interfaces were easy to use and navigate, and they found the features intuitive and helpful. Additionally, user satisfaction was high, with participants appreciating the application's straightforward design and the relevance of the features. Results show that user satisfaction correlates strongly with ease of use.

These results suggest that the application meets its objectives and provides a positive user experience. However, some fixes must be done to improve the application's reliability.

5 Conclusions

In this research, a mobile application was designed, developed, and evaluated to enable Panamanians to track the greenhouse gas emissions generated by their daily home activities.

The findings of this research underscore the significant role mobile applications can play in environmental conservation, particularly in the realm of green- house gas reduction. By integrating real-time data visualization and personalized feedback mechanisms, the application not only engaged users effectively but also fostered a profound sense of individual responsibility and provided actionable insights into their environmental impacts. Participants reported a heightened awareness of how their daily activities contribute to both direct and indirect greenhouse gas emissions. This increase in environmental consciousness is crucial as it represents an essential initial step toward catalyzing broader societal changes. These changes are imperative for achieving substantial and lasting reductions in environmental impact. This study illustrates that targeted digital interventions can significantly influence public behavior in ways that are both measurable and scalable, potentially driving the collective action needed to ad- dress global climate challenges.

The insights from the application's data can significantly influence policy decisions and strategies. By providing a detailed breakdown of emission sources, policymakers in Panama can better target interventions and create more effective environmental regulations and standards. Future collaborations with environmental organizations, educational institutions, and governmental bodies in Panama will enhance the application's impact and provide a more comprehensive approach to tackling climate change.

Continued research and development are essential to enhance the application's capabilities and extend its reach. Future versions could incorporate ma- chine learning algorithms to predict user behavior and suggest personalized, context-aware strategies for reducing emissions. Integrating the application with smart home technologies could also automate certain energy-saving aspects, making sustainable living more seamless and effective.

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