

Direct flow between distribution centers for multi-objective supply chain design

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Abstract

This paper reviews the problem of designing a multi-objective supply chain called Capacitated Fixed Cost Facility Location Problem with Transportation Choices (CFCLP-TC). We solve this multi-objective problem using the epsilon-constraint approach. The models with and without this transshipment feature are implemented in GAMS and solved with CPLEX.

Keywords: Multi-objective Optimization, ϵ -constraint, Facility Location, Pareto Front

1. Introduction

Supply Chain Management (SCM) is the process of planning, implementing and controlling the operation of the supply chain efficiently (Chopra 2010). SCM spans all movements and storage of raw materials, work-in-process inventory, and finished goods from the point of origin to the point of consumption (Melo et al. 2009). Part of the planning processes in SCM aim at finding the best possible supply chain configuration so that all operation can be performed in an efficient way. The Capacitated Fixed Cost Facility Location Problem with Transportation Choices (CFCLP-TC) proposed by (Olivares 2007) is a combinatorial optimization problem for supply chain design. It is an extension of the FCLP (Fixed-Cost Facility Location Problem) as a bi-objective mixed-integer program. It is based in a two-echelon system for the distribution of one product in a single time period with two objectives: to minimize cost and to minimize the

transportation time from plants to customers. This approach considers several alternatives to transport the product from one facility to the other in each echelon of the network. The criterion of cost is an aggregate function of variable cost and fixed cost. The function of time represents the longest time it may take to transport a product from any plant to any customer. Differently from similar works in the literature, the aim here is to provide to the decision maker with a set of non-dominated alternatives to allow her to decide. Some qualitative information only known by the decision maker may motivate the selection of one of these alternatives. This paper reviews the design of the supply chain by modifying the original model to allow direct flow between distributions centers. For the study of this problem and the proposed variation, instances of different sizes were used. We compare the results on the basis of two types of metrics, the first one is the R_{pos} (set of no dominated solutions) used by (Altiparmark et al. 2006), and the second are called D_{avg} and D_{min} (metric of the mean and minimal difference) proposed by (Olivares 2007), to compare two bi-objective Pareto fronts. The models were implemented in GAMS 23.6.2 and solved with CPLEX 12. Additionally, the run times for both models, the original and the variation, are compared. This paper is divided into five sections as follows: the first section presents a general introduction to the work. The second section shows the literature review of the subject in order to identify the gap that this work fills. The third section presents an overview of the problem. The fourth section shows details of the computational experiment, explains the metrics used to evaluate the Pareto fronts, and presents the results of the computational implementation. Finally, the fifth section presents the conclusions and proposals to carry out further work.

2. - Literature review

Historically, researchers have focused on the design of distribution systems (Geoffrion and Powers 1995) without considering as a whole supply chain. Typically discrete location models were proposed to include additional features. (Aikens 1985) reviews some important integer-linear mixed formulations for production-distribution systems. However, these models had limited scope and could not cope with realistic supply chain structures. (Geoffrion and Powers 1995) proposes the inclusion of relevant features for Supply Chain Management (SCM) in the facility location models that gradually began to be considered. (ReVelle and Laporte 1996) suggested the inclusion of additional features in facility location models such as the inclusion of new objectives (maximum investment return) and decisions regarding the selection of equipment for new installations. The capacitated facility location problem (CFLP) is a well-known combinatorial optimization problem. It consists in deciding which facilities to open from a given set a potential facility locations and how to assign customers to those facilities. The objective is minimizing total fixed and shipping cost. Applications of the CFLP include location and distribution planning, lot sizing in production planning and telecommunication network design as mentioned in (Klose and Gortz 2006). Numerous heuristics and exact algorithms for the CFLP have been proposed in the literature. Heuristic solution methods as well as approximation algorithms were proposed by (Kuehn and Hamburger 1963, Khumawala 1974, Korupolu et al. 1998). Tabu Search methods for the related p -median problem and the CFLP with single source were developed by (Rolland et al. 1996, Delmaire et al. 1999). Exact solution methods based on the Benders decomposition algorithm are considered in (Magnanti and Wong 1981, Wetges 1996). Polyhedral results for the CFLP have been obtained by (Leung and Magnanti 1989). (Aardal 1998) uses these results in a branch-and-cut algorithm for the CFLP. A variety of heuristic and exact solution approaches for the CFLP, however, use Lagrangean Relaxation.

Moreover, several variants of the CFLP have been investigated. (Laporte et al. 1994) formulated a stochastic integer linear programming model for the CFLP with stochastic demands. A branch-and-cut approach was applied to find the optimal solution of the problem. (Tragantalerngsak et al. 1997) formulated the mathematical model of the two-echelon SSCFLP and considered six Lagrangian relaxation-based approaches for the solution. In recent years, many meta-heuristic approaches have been applied to combinatorial optimization problems successfully, such as Simulated Annealing (SA), Genetic Algorithms (GAs), Tabu Search (TS), Ant Colony Optimization (ACO). Some recent works in this field include those presented by (Moncayo-Martinez and Zhang 2011), in which they use an ant colony approach for the design of a supply chain. (Wei-Chang et al. 2011) proposed a memetic algorithm for a problem in a multi-stage supply chain. (Rajesh et al. 2011) proposed a simulated annealing algorithm for an allocation problem. The bi-objective location problems are an extension of classic locations problems. These problems are bi-objective median, knapsack, quadratic, covering, unconstrained, location-allocation, hub, hierarchical, competitive, network, obnoxious and semi-obnoxious location problems. Considering capacities in location problems, there are capacitated and uncapacitated problems in the literature. For instance, (Myung et al. 1997) have considered an uncapacitated facility location problem with two maximum objectives net profit and return on investment and modeled it as parametric integer program with fractional and linear objectives. (Villegas et al. 2006) modeled a supply network as a bi-objective uncapacitated facility location problem, with minimum and maximum objectives (cost and coverage). In contrast, (Galvao et al. 2006) developed an extension of the capacitated model to deal with locating maternity facilities with minimum objectives (distance traveled and load imbalance). (Costa et al. 2008) utilized a different bi-criteria approach to the single allocation hub location problem. This approach has two objectives, the first is a minimum form (cost), while the second objective (process time) has two alternative forms. The Capacitated Fixed Cost Facility Location Problem with Transportation Choices (CFCLP-TC) proposed by (Olivares 2007) is an extension of the CFLP with a bi-objective mixed-integer program approach (cost and time). It is based in a two-echelon system for the distribution of one product in a single time period. This approach considers several alternatives to transport the product from one facility to the other in each echelon of the network. Differently from similar works in the literature the aim here is to provide the decision maker with a set of non-dominated alternatives to allow her deciding. Some qualitative information only known by the decision maker may motivate the selection of one of these alternatives. In combinatorial optimization, the consideration of multiple objectives has received wide attention; in specific the multi-objective combinatorial optimization (MOCO) has become a very active area of research (Ehrgott and Gandibleux 2004). This approach has been extensively studied in the literature, (Bornstain et al. 2012) develops an algorithm with re-optimization for one problem with a cost and several bottleneck objective functions, (Bérubé et al. 2009) propose an exact epsilon-constraint method for a special case of MOCO called bi-objective combinatorial optimization (BOCO) for the traveling salesman problem with profits. The ϵ -constraint method is a MOCO solution method based on a scalarization where one of the objective functions is optimized while all the other objective functions are bounded in the form of additional constraints (Ehrgott 2005). The ϵ -constraint method guarantees to find weakly efficient solutions. However when we have an optimal solution, it is not easy to verify if this solution is either an efficient solution or it is not. (Cardona-Valdés et al. 2011) propose an algorithm based on the fusion of the ϵ -constraint and the L-shaped method for a bi-objective supply chain design problem with uncertainty. Likewise

(Salazar-Aguilar et al. 2011) uses the ϵ -constraint approach for a bi-objective programming model for designing compact and balanced territories in commercial districting. In our implementation of the ϵ -constraint method we select one objective function as the main objective function and another objective function is transformed to another constraint. For variations in the direct flow to plants (i) to customer (k) compared with the original model, the same approach to generate the Pareto Front is used. (Mula et al. 2010) established that one of the main contributions that remain to be done in the field of mathematical models for designing supply chains is the consideration of the different distribution channels in these models and considering the different types of configurations for product flow. The study of the variations of the problem (CFCLP-TC) will establish the importance of the choice of distribution channels under the assumptions described above so that this problem is closer to real situations that are demanded in the supply chain process and location of modern facilities. Thus, the investigation in this paper contributes the development of state of art in an area that has not been sufficiently explored.

3. - Problem Description

The Capacitated Fixed Cost Facility Location Problem with Transportation Choices (CFCLP-TC) proposed by (Olivares 2007), is based on a two-echelon system for the distribution of one product in a single time period. In the first echelon, the product is sent from manufacturing plants (i) to distribution centers (j). The second echelon corresponds to the flow of product from distribution centers (j) to customers (k).). The outline of the distribution network is shown in Figure 1.

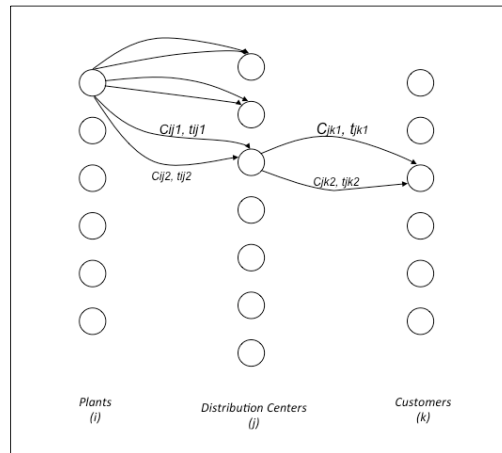


Figure 1 Schematic of the original Capacitated Fixed Cost Facility Location Problem with Transportation Choices (CFCLP-TC)

In this problem, the number and location of plants (i) and customers (k) are known a priori. This problem includes a further decision on the selection of transportation channels between facilities, using a bi-objective approach that simultaneously minimizes the time for transporting the product from plants to customers and the combined costs of locating facilities and transportation. This solution approach builds a set of alternative non-dominated solutions for the decision maker. This problem has a set of possible locations for the opening of distribution centers (j) and their number is not defined. Each candidate site has a fixed cost for opening a facility, and each site has limited capacity. Manufacturing plants have limited capacity.

This paper proposes to compare the original model (CFCLP-TC) with our proposal, which allows the exchange of product between the distributions centers (j) – (p). For some alternatives in this variation the path of plants (i)-distribution centers (j)-customers (k) would compete directly with the alternative flow of plants (i)-distribution centers (j)-distribution centers (p)-customers (k). The main idea is that for some cases it is cheaper and faster to send a product from one distribution center (j) to another distribution center (p) and then send it to the customers (k). The outline of the distribution network is shown in Figure 2. The proposal explores a configuration of the new supply chain that has not been considered in the literature.

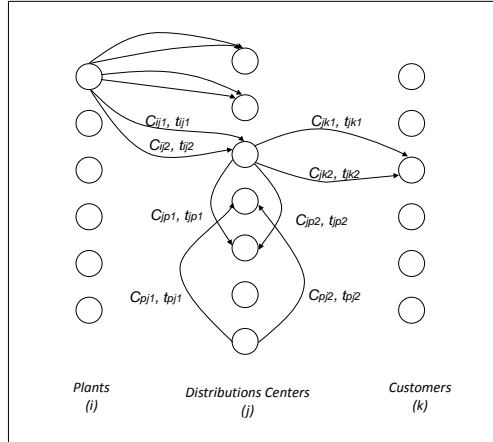


Figure 2 Schematic of the Capacitated Fixed Cost Facility Location Problem with Transportation Choices (CFCLP-CT) with flow between distribution centers

Model:

$$\min(f_1, f_2)$$

$$f_1 = \sum_{i \in I} \sum_{j \in J} \sum_{l \in LP_{ij}} CP_{ijl} X_{ijl} + \sum_{j \in J} \sum_{k \in K} \sum_{l \in LW_{jk}} CW_{jkl} Y_{jkl} + \sum_{j \in J} \sum_{p \in P} \sum_{l \in LS_{jp}} C_{jpl} R_{jpl} + \sum_{j \in J} \sum_{p \in P} \sum_{l \in LS_{pj}} C_{pjl} R_{pjl} + \sum_{j \in J} F_j Z_j \quad (1)$$

$$f_2 = T \quad (2)$$

Subject to

$$T - E_j^1 - E_j^2 \geq 0 \quad \forall j \in J \quad (3)$$

$$T - E_3 \geq 0 \quad \forall j \in J \quad (4)$$

$$E_j^1 - TP_{ijl} A_{ijl} \geq 0 \quad \forall i \in I, j \in J, l \in LP_{ij} \quad (5)$$

$$E_j^2 - TW_{jkl} B_{jkl} \geq 0 \quad \forall j \in J, k \in K, l \in LW_{jk} \quad (6)$$

$$\sum_{l \in LS_{jp}} C_{jpl} \leq M(1 - \delta_{jp}) \quad \forall j \in J, p \in P \quad (7)$$

$$\sum_{l \in LS_{pj}} C_{pjl} \leq M(1 - \delta_{pj}) \quad \forall j \in J, p \in P \quad (8)$$

$$E_3 - \sum_{l \in LP_{ij}} A_{ijl} TP_{ijl} + \sum_{l \in LS_{jp}} C_{jpl} TS_{jpl} + \sum_{l \in LW_{pk}} B_{pkl} TW_{pkl} \geq -M\delta_{jp} \quad \forall i \in I, j \in J, p \in P, k \in K \quad (9)$$

$$E_3 - \sum_{l \in LP_{ij}} A_{ijl} TP_{ijl} + \sum_{l \in LS_{pj}} C_{pjl} TS_{pjl} + \sum_{l \in LW_{pk}} B_{jkl} TW_{jkl} \geq -M\delta_{pj} \quad \forall i \in I, j \in J, p \in P, k \in K \quad (10)$$

$$\sum_{j \in J} \sum_{l \in LS_{jp}} C_{jpl} + \sum_{p \in P} \sum_{l \in LS_{jp}} C_{pjl} \leq 1 \quad \forall j \in J, p \in P \quad (11)$$

$$\sum_{p \in P} \sum_{l \in LS_{jp}} C_{jpl} + \sum_{p \in P} \sum_{l \in LS_{jp}} C_{pjl} \leq 1 \quad \forall p \in P, \quad (12)$$

$$\sum_{j \in J} \sum_{l \in LW_{jk}} Y_{jkl} = D_k \quad \forall k \in K \quad (13)$$

$$\sum_{j \in J} \sum_{l \in LP_{ij}} X_{ijl} = MP_i \quad \forall i \in I \quad (14)$$

$$MW_j Z_j - \left(\sum_{j \in J} \sum_{l \in LW_{jk}} Y_{jkl} + \sum_{j \in LS_{jp}} R_{jpl} - \sum_{j \in LS_{pj}} R_{pjl} \right) \geq 0 \quad \forall j \in J \quad (15)$$

$$\sum_{i \in I} \sum_{l \in LP_{ij}} X_{ijl} + \sum_{p \in P} \sum_{l \in LS_{jp}} R_{pjl} - \sum_{k \in K} \sum_{l \in LW_{jk}} Y_{jkl} - \sum_{p \in P} \sum_{l \in LS_{jp}} R_{jpl} = 0 \quad \forall j \in J \quad (16)$$

$$\sum_{j \in J} \sum_{l \in LW_{jk}} B_{jkl} = 1 \quad \forall k \in K \quad (17)$$

$$\sum_{l \in LP_{ij}} A_{ijl} \leq 1 \quad \forall i \in I, j \in J \quad (18)$$

$$\sum_{l \in LW_{jk}} B_{jkl} \leq 1 \quad \forall j \in J, k \in K \quad (19)$$

$$\sum_{l \in LS_{jp}} C_{jpl} \leq 1 \quad \forall j \in J \quad (20)$$

$$\sum_{l \in LS_{pj}} C_{pjl} \leq 1 \quad \forall j \in J \quad (21)$$

$$X_{ijl} - A_{ijl} \geq 0 \quad \forall i \in I, j \in J, l \in LP_{ij} \quad (22)$$

$$Y_{jkl} - B_{jkl} \geq 0 \quad \forall j \in J, k \in K, l \in LW_{jk} \quad (23)$$

$$R_{jpl} - C_{jpl} \geq 0 \quad \forall j \in J, l \in LS_{jp} \quad (24)$$

$$R_{pjl} - C_{pjl} \geq 0 \quad \forall j \in J, l \in LS_{pj} \quad (25)$$

$$MP_i A_{ijl} - X_{ijl} \geq 0 \quad \forall i \in I, j \in J, l \in LP_{ij} \quad (26)$$

$$MW_j B_{jkl} - Y_{jkl} \geq 0 \quad \forall j \in J, k \in K, l \in LW_{jk} \quad (27)$$

$$MW_j C_{jpl} - R_{jpl} \geq 0 \quad \forall j \in J, l \in LS_{jp} \quad (28)$$

$$MW_j C_{pjl} - R_{pjl} \geq 0 \quad \forall j \in J, l \in LS_{pj} \quad (29)$$

$$T, E_j^1, E_j^2, E_3, X_{ijl}, Y_{jkl}, R_{jpl} \geq 0 \quad \forall i \in I, j \in J, k \in K, l \in LP_{ij}, l \in LW_{jk}, l \in LS_{jp} \quad (30)$$

$$Z_j, A_{ijl}, B_{jkl}, C_{jpl}, \delta_{jp} \in \{0, 1\} \quad \forall i \in I, j \in J, k \in K, l \in LP_{ij}, l \in LW_{jk}, l \in LS_{jp} \quad (31)$$

Equations (1) and (2) are the objective functions that look for the best possible cost and shortest time. The constraints (3) calculate the longest total time from any (i) to any (k). The constraints (4) calculate the longest total time. The constraints (5) and (6) calculate the transportation time in each echelon respectively. The constraints (7) and (8) establish a condition if - then to determine the longest time in the flow of product from (i) to (k). The constraints (9) and (10) complete the if-then condition to calculate the longest time in the flow of product from (i) to (k).

Table 1: Instances Sizes

Instances sizes	Integer variables in the original approach	Integer variables in the approach that allows flow between distribution centers (j)-(p)
5-5-5-2	105	355
5-5-5-5	255	805
5-10-10-2	320	1310
5-10-15-2	410	1410
5-10-20-2	510	1510

Constraints (11) restrict multiple product flows through distribution centers (j) so that it can only be done once. Constraints (12) state that the exchange of product between (j) - (p) do not make a cycle. Constraints (13) allow the satisfaction of the needs for each customer. Constraints (14) mean we cannot exceed the capacity of each plant (i). Constraints (15) make that the capacity of distributions centers (j) cannot be exceed. Constraint (16) provides a balance between the quantities transported in each echelon. The constraints in (17) state that customers (k) can only be provided by a single source. The constraints (18), (19), (20) and (21) provide that the

transportation of the product can only be done through a single arc. The constraints (22), (23), (24) and (25) establish that an arc is inactive if there is no flow through it. The constraints (26) and (27), (28) and (29) provide that the product shipment will be made only through active arcs. The constraints (30) and (31) set the domain of the variables in the model.

4. - Computational Experiment

For the process of computational experiments five sets of instances of the following sizes were used as shown in Table 1.

The encoding of the instance is as follows: The first index indicates the number of plants (i), the second index indicates the number of distribution centers (j), the third index indicates the number of customers (k), and finally the fourth index indicates the number of arcs between nodes in each echelon. In each size 5 instances were tested. The experiments were performed on a workstation machine with a Core™ 2 Duo T8300 CPU at 2.40 GHz with 12 GB of RAM, all under an operating system of 64 bits windows (seven).

4.2. - Metrics for evaluations

To make the comparison of the Pareto fronts with the original approach and with flow between distribution centers, the metric $R_{pos}(P_i)$ proposed by (Altiparmark et al. 2006) was used. Additionally, we registered the average number of Pareto-optimal solutions in each front. To calculate the $R_{pos}(P_i)$ consider P_1 and P_2 be the sets of Pareto-optimal solutions obtained from each model, and P be the union of the sets of Pareto-optimal solutions (i.e $P = P_1 \cup P_2$) such that it includes only non-dominated solutions Y 's. The ratio of Pareto-optimal solutions in P_i that are not dominated by any other solutions in P is calculated as follows:

$$R_{pos}(P_i) = \frac{|P_i - \{X \in P_i | \exists T \in P: Y < X\}|}{P_i} \quad (33)$$

Where $Y < X$ means that the solution X is dominated by solution Y . The higher the ratio $R_{pos}(P_i)$ is, the better the solution set P_i is. Similarly, we used the metrics proposed by (Olivares-Benitez et al. 2012) called D_{avg} and D_{min} . These were developed to give practical meaning to the comparison of sets point by point. Then D_{avg} computes an average rate deviation of the objective function f_1 for each value of f_2 , which is in the set T .

$$D_{avg} = \frac{\sum_{t \in T} \frac{f_1(s): f_2(s) = t}{f_1(s'): f_2(s') = t}}{|T|} \quad \forall s \in S_1, s' \in S_2 \quad (34)$$

$$D_{min} = \min_{t \in T} \frac{f_1(s): f_2(s) = t}{f_1(s'): f_2(s') = t} \quad \forall s \in S_1, s' \in S_2 \quad (35)$$

The metric D_{avg} indicates the quality of a set compared to another. The following relationship can be established:

$$\text{If } D_{avg} \begin{cases} < 1 S_1 \text{ is better than } S_2 \\ > 1 S_1 \text{ is worse than } S_2 \\ = 1 S_1 \text{ is similar to } S_2 \end{cases}$$

4.3. - Results

Table 2 shows the results of the variation that allows the flow between distribution centers (j) – (p). D_{avg} is greater than 1 in all cases; this indicates a lower quality of the Pareto fronts of this variation compared with the original model. D_{min} in all cases indicates the smallest difference comparing both fronts and gives us an indication of the difference of the fronts compared. With respect to R_{pos} shows that the variation to the model presents values lower than 1 in all cases compared with the original model. The R_{pos} values in the original model are on average of 1 with respect to the variation, this indicates that the original model presents always better Pareto fronts. With respect to processing time, some examples show the comparison: for instances 5-5-5-2 the computational time increased an average of 460%; for instances 5-5-5-5 the computational time increased an average by 560% over the original model. For the analysis of this variation we tested only the two smallest instances because the processing time required for evaluating the variation is very large. Instance 5-5-5-5 required on average 34 hours getting the results, but one instance 5-10-10-2 after 143 hours of processing did not find a result, so that we determined not following the tests for the rest of the instances.

Table 2: Results

Size	Instance	Original approach		Flow between (j) and (p)		D_{avg}	D_{min}	Time with original approach (Seconds)	Time with flow between (j) and (p) (Seconds)
		S_i	$R_{pos}(S_i)$	S_i	$R_{pos}(S_i)$				
5_5_5_2	1	33	1	1	0.33333333	1.0165715	1	11.631	326.195
	2	31	1	1	0.03225806	1.01402981	1	20.896	292.527
	3	31	1	0	0	1.04683427	1.02795867	8.728	245.921
	4	32	1	0	0	1.06735052	1.006421	13.499	1215.217
	5	30	1	0	0	1.08324319	1.03670392	9.841	898.683
5_5_5_5	1	38	1	0	0	1.02172283	1.00771899	187.27	52861.828
	2	39	1	0	0	1.01398614	1.00201322	112.811	382637.904
	3	39	1	6	0.15384615	1.00778561	1	3944.193	122663.847
	4	40	1	0	0	1.01458474	1.00033388	218.698	43666.763
	5	40	1	2	0.05	1.01185138	1	2234.115	131359.178

5. - Conclusions

(Melo et al. 2009) defines the implementation of the supply chain as the process of planning, implementing and operationally controlling the supply chain in an efficient manner. This aspect is defined in the context of tactical decisions that allow more efficiency in the full cycle of manufacture. The work developed in this research explores the selection of distribution channels that has not been incorporated into mathematical models of supply chain design (Mula et al. 2010, Olivares-Benitez et al. 2012, Melo et al. 2009, Bozart et al. 2009). The CFCLP-TC problem proposed in (Olivares 2007 and Olivares-Benitez et al. 2012) incorporates a novel way to select the transportation alternatives in the context of a two-echelon problem considering: plants, distribution centers and customers. However the changes proposed in this paper can bring theoretical models to real applications, as it considers situations that may occur in real situations. The results in this works determined that this approach provides worse Pareto fronts than the original model and therefore higher costs for the same time points. This approach required longer processing times as the size of the instances grows making difficult to solve situations that are not rare in practice. However, one aspect that the model does not consider is the level of customer service that may justify the exchange of products between distribution centers. This proposal makes it possible to explore a configuration of innovative supply chain that has not been

considered in the revised literature. It is clear that the new approach produced an increase in the required processing time. The findings and conclusions presented are based only on instances that were tested which in a context of real implementation are small. It is possible that the results of the Pareto front for larger instances could be different, therefore it is important to determine these fronts, and however the impossibility of doing so with exact methods requires us to try to get them through heuristics and metaheuristics. In the revised literature the Lagrangian relaxation method is widely used to solve similar problems (Lidestam and Rönnqvist 2011), and this may be applied to the problem raised in this work. Another approach is the use of genetic algorithms (Gen et al. 2006) for a similar problem found in the literature. Evolutionary algorithms like Non-dominated Sorting Genetic Algorithm (NSGA-II) and Strength Pareto Evolutionary Algorithm (SPEA - II) are widely used in similar problems also (Lin et al. 2009).

Acknowledgements

Finally the authors wish to express their thanks to the “Universidad Politécnica de Tulancingo”, for the support received in the development of this work.

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