Scheduling in flow shop with sequence-dependent setup times: literature review and analysis

Moacir Godinho Filho*

Department of Industrial Engineering,
Federal University of São Carlos,
Via Washington Luiz, km 235 – Postal Box 676,
13.565-905 São Carlos-SP, Brazil
E-mail: moacir@dep.ufscar.br
Corresponding author

Márcia de Fátima Morais,
Thays Josyane Perassoli Boiko,
Hugo Hissashi Miyata and
Fernando Willian Rodrigues Varolo

Department of Industrial Engineering,
State University of Paraná-FECILCAM/
Federal University of São Carlos,
Avenue Comendador Norberto Marcondes, 733,
87303 – 100 Campo Mourão-PR, Brasil
E-mail: marciafmorais@yahoo.com.br
E-mail: thaysperassoli@bol.com.br
E-mail: hugomiyata7@hotmail.com
E-mail: fernandovarolo@hotmail.com

Abstract: This research focuses on the flow shop production scheduling problem with sequence-dependent setup times. The study reviews and analyses the methods used in the literature to solve this problem. The analyses were performed using the number of papers published during the study period, the approach used to develop solution methods, the type of objective function and performance criterion adopted, and the additional constraints considered. It were identified and analysed 83 papers that address the flow shop scheduling problem with setup times separated from processing times. The results of the review and analysis showed several opportunities for future research on this topic, including

1 working with setups dependent on batch sequences
2 using bi- and multi-criteria functions related to the flow time objective
3 adding practical constraints faced by production systems.

Keywords: production scheduling; flow shop; sequence-dependent setup times.

Reference to this paper should be made as follows: Godinho Filho, M., de Fátima Morais, M., Boiko, T.J.P., Miyata, H.H. and Varolo, F.W.R. (xxxx) 'Scheduling in flow shop with sequence-dependent setup times: literature review and analysis', *Int. J. Business Innovation and Research*, Vol. X, No. Y, pp.000–000.

Biographical notes: Moacir Godinho Filho is a Professor in the Department of Industrial Engineering, Federal University of São Carlos, Brazil. He received his BS from Federal University of São Carlos, MBA from Fundação Getúlio Vargas, Brazil, MS and PhD from Federal University of São Carlos. He was a Visiting Scholar at Department of Industrial and Systems Engineering, University of Wisconsin at Madison, USA and also at Edward P. Fitts Department of Industrial and Systems Engineering, North Carolina State University, USA. He has about 50 papers published in journals with selective review process. His areas of interest are: production planning and control, lead time reduction, logistics and supply chain management.

Márcia de Fátima Morais is a Professor in the Department of Industrial Engineering of UNESPAR/FECILCAM, Campo Mourão/PR, Brazil. She received his BS from UNESPAR/FECILCAM (2002) and MS from Universidade de São Paulo (USP). She is currently a PhD student at the Department of Industrial Engineering, Federal University of São Carlos, Brazil. She is also a Researcher from the Research Group on Processes and Operations Management.

Thays Josyane Perassoli Boiko is a Professor in the Department of Industrial Engineering of UNESPAR/FECILCAM, Campo Mourão/PR, Brazil. She received his BS from UNESPAR/FECILCAM (2002) and MS from Universidade de São Paulo (USP). She is currently a PhD student at the Department of Industrial Engineering, University of São Paulo, Brazil. She is also a Researcher from the Research Group on Processes and Operations Management.

Hugo Hissashi Miyata received his BS from UNESPAR/FECILCAM (2011). He also participates of the Research Group on Processes and Operations Management.

Fernando William Rodrigues Varolo is doing his BS from UNESPAR/FECILCAM (2011). He also participates from the Research Group on Processes and Operations Management.

1 Introduction

Analysing the research on solutions to flow shop production scheduling problems, including Allahverdi et al. (1999), Gupta and Stafford (2006) and Allahverdi et al. (2008), shows that considering these problems and explicitly treating setup times/costs began in the late 1960s, based on progressively increasing interest from researchers on this topic.

According to Burtseva et al. (2010), the time that a job spends on a machine includes three phases: setup, processing, and removal. Most investigations dedicated to production planning and scheduling assume that the setup and removal times are negligible or included in the job processing time. This hypothesis simplifies the analysis, making these problems solvable as standard scheduling problems. Conversely, according to Sharma (2011), this assumption adversely affects the solution quality for many applications that require explicit setup treatment. According to Pinedo (2008), explicit treatment of setup time is required in most applications because machine setup time is often a significant factor for production scheduling. It may easily consume over 20% of the available machine capacity if it is not well handled. To the publication by Allahverdi et al. (2008), the increased interest in scheduling problems with setup times separated from processing times has led to over 40 articles published per year. According to Urlings (2010, p.04), "The existence of setup times is a common phenomenon, both in industry and in the literature". An extensive and updated review of the literature focusing on papers that consider flow shop scheduling with sequence-dependent setup times becomes relevant to research in this area, as it may help researchers focus their efforts.

The goal of this research is to identify and analyse the available literature on the flow shop scheduling problem which considers sequence-dependent setup time (FS-SD). The setup time can be required after a job (FS-SD-job) or after a job batch (FS-SD-batch). This study presents state-of-the-art methods for solving this problem. This study can help business managers and schedule practitioners better understand scheduling, production scheduling concepts, and scheduling practice in flow shop systems. The present literature review is also useful for presenting some literature gaps in the field. Talib et al. (2012) present an excellent literature review.

The article is structured in six sections. After summarising the background research and presenting the research objectives, the theoretical framework is laid out. The third section presents the research methodology. The fourth section details the work performed in flow shop with setup times separated from processing times and dependent on the sequence, followed by a summary of the main features of the work identified in the literature. Section 5 analyses the published works. Section six summarises and concludes the research.

2 Basic concepts

Production scheduling is one function performed by the planning and production control (PPC), which, according to Fernandes et al. (2009) and Zacarelli (1987), is defined as an administrative function that aims to develop plans that guide and control production.

A production scheduling problem is perceived as "a problem of n jobs $\{J_1, J_2, \ldots, J_j, \ldots, J_n\}$ that must be processed on m machines $\{M_1, M_2, \ldots, M_k, \ldots, M_m\}$" [French, (1982), p.5]. According to Johnson and Montgomery (1974, p.322), "Scheduling problems consists of determining the order or sequence in which the machines will process the jobs so as to optimize some measure of performance". Production scheduling thus "can be defined as the allocation of resources over time to perform jobs to better meet a group of pre-defined criteria" [MacCarthy and Liu, (1993), p.59].

According to MacCarthy and Liu (1993, p.62) and Allahverdi et al. (2008, p.988), the production scheduling problems are classified as follows: single machine; parallel machine; flow shop; permutational flow shop; job shop; hybrid flow shop; hybrid job shop; and open shop (MacCarthy and Liu, 1993). This work focuses on the flow shop environment. "A flow shop is characterized by a more-or-less continuous and uninterrupted flow of jobs through multiple machines in series. In such a shop, the flow of work is unidirectional because all jobs follow the same technological routing through the machines. In a flow shop, jobs or batches of jobs have a flow pattern using identical machines" [Gupta and Stafford, (2006), p.700].

According to MacCarthy and Liu (1993), production scheduling is always performed to satisfy a criterion or set of performance. The main optimisation criteria used in scheduling problems are the following (MacCarthy and Liu, 1993; Allahverdi et al., 1999, 2008): date of completion of job Jj or completion time (Cj); flow time or job flow (Fj); wait time (Wj); lateness or advance (Lj); tardiness or delay (Tj); makespan (Cmax); mean completion time (ΣCj/n); total completion time (ΣCj); total weighted completion time (ΣwjCj); total flow (ΣFj); total weighted flow time (ΣwjFj); mean time flow (ΣFj/n); maximum lateness (Lmax); total lateness (ΣLj); weighted total lateness (ΣwjLj); earliness or negative lateness (Ej); maximum tardiness (Tmax); total tardiness (ΣTj); mean tardiness (ΣTj/n); total weighted tardiness (ΣwjTj); total wait time (ΣWj), mean time to wait (ΣWj/n); total time weighted wait (ΣwjWj); total wait time (ΣWj); mean wait time (ΣWj/n); weighted total earliness (ΣwjEj); number of late jobs (ΣUj); total setup costs (TSC); total setup time (TST or ΣSj); inventory costs (IC); transportation costs (TC); total cost of opportunity (TCO); total cost utility (TCU); total idle time (TIT); reduction of work in process (WIP); time blocking of the machines (MBT); compliance with deadlines (CD); cycle time (MCT); production costs (PC); rental costs (RC); and level service (LS). The literature on manufacturing performance measurement underscores the importance of operational performance and aggregate organisational measures, as in Gomes et al. (2007). Malinin (2010) presents a method for clients to transform business goals into a set of engineering problems that, when solved, make the business goals achievable.

The problem with practical production scheduling is that many situations may occur. Adding these possibilities to the scheduling problem would be virtually impossible. Researchers generally consider work orders with hypotheses to constrain the subject and treat specific situations. The production scheduling problem hypotheses can be divided into assumptions about jobs and/or job groups, machinery and political operations, as in Gupta and Stafford (2006).

All production systems have several limitations that may compromise or optimise their performance indicators, the tools used to analyse and monitor delivery dates, the order processing speed and the idle time. Incorporating restrictions into the basic production scheduling problem increases its complexity. This research examines one such restriction, emphasising the times associated with preparing a machine or the process to process a job or batch job (i.e., the setup times).

For cases where the setup time is treated separately from the job processing times, based on Cheng et al. (2000) and Allahverdi et al. (2008), there are two types of problems:

1 setup time sequence-dependent of the jobs or batch jobs

2 setup times sequence-independent of the job or batch job execution sequence.

"Setup times sequence-dependent occur when the setup time depends on both the job or batch job to be processed and the previous job or batch jobs, while times setup times sequence-independent occur when the setup time depends only on the job or batch jobs to be processed" (Allahverdi, Gupta and Aldowaisan , 1999, p. 219).

The solution methods for production scheduling problems are divided into three broad categories:

1 optimal solution methods, which "are methods that generate an optimal schedule in accordance with the performance criterion adopted" [MacCarthy and Liu, (1993), p.64].

2 heuristic methods, which "are methods that seek to produce a solution close to the optimal solution in an acceptable computational time" [MacCarthy and Liu, (1993), p.66]

3 metaheuristic methods, which are the highest level, thus creating a process to avoid local minima and perform a search area of the robust solution to a problem.

3 Research methodology

The present literature review is a theoretical/conceptual qualitative research study, according to Bryman (1989). According to Martins (2010), the qualitative approach has the following primary characteristics: subjective interpretation, context outline, multiple evidence sources, and importance in organisational reality. In this approach, variables are defined before observation or experimentation.

This study focuses on identifying published studies that develop methods for Production Scheduling in flow shop systems with setup times separated from processing times, which are dependent of the job or batch job execution sequence, and analyse the content of these works to identify the current state-of-the-art in this research area. This study includes research papers published by early 2012.

The databases used were Compendex, Emerald, Google Scholar, Scirus and Scopus, and the keywords were flow shop, setup times, setup times separated from process times, setup times dependent on the sequence, restrictions and additional restrictions. Extensive keyword combinations were also used to identify work in the literature. The review presented here considered only studies published in English. Furthermore, more than 30 journals in operations research, management, production management and applied sciences were consulted individually during this research.

To facilitate discussing the results, which in this study was done using percentage, the studies were classified into two major groups:

- papers that address the flow shop scheduling problem with sequence-dependent setup time required between jobs (FS-SD-jobs)
- papers that address the hybrid flow shop scheduling problem with sequence-dependent setup time required between batches (FS-SD-batch).

For each paper, relevant characteristics were extracted:

a solution approach: optimal solution, heuristic and meta-heuristic

b objective function: mono, bi or multi-criteria

c criteria(s) optimisation

d additional restrictions.

4 The literature review

This section presents papers that address the FS-SD-job and FS-SD-batch problem.

In the literature review, we found 63 studies that addressed the FS-SD-job problem: Gupta (1969), Corwin and Esogbue (1974), Uskup and Smith (1975), Gupta (1975), Bellman et al. (1982), Rothblum (1983), Gupta and Darrow (1985), Gupta (1986), Gupta and Darrow (1986), Srikar and Ghosh (1986), Szwarc and Gupta (1987), Rajagoplan and Karimi (1987), Gupta (1986), Simons (1992), Vob (1993), Bolat (1994), Bolat et al. (1994), Gupta et al. (1995), Das et al. (1995), Rios-Mercado and Bard (1996), Rajendran and Ziegler (1997), Parthasarathy and Rajendran (1997a, 1997b), Rios-Mercado and Bard (1998a, 1998b), Hwang and Sun (1998), Sonmez and Baykasoglu (1998), Rios-Mercado and Bard (1999a, 1999b), Normam (1999), Demirkol and Uzsoy (2000), Sun and Hwang (2001), Rajendran and Ziegler (2003), Rios-Mercado and Bard (2003), Maddux and Gupta (2003), Andrés et al. (2005), Gajpal et al. (2005), Ruiz et al. (2005), Tseng et al. (2006), Huang and Yang (2008), Lo et al. (2008), Mansouri et al. (2008), Ruiz and Stützle (2008), Sajadi et al. (2008), Yang and Liu (2008), Zandieh et al. (2008), Dhingra and Chandna (2009), Dong et al. (2009), Eddaly et al. (2009), Maboudian and Shafaei (2009), Martin (2009), Dhingra and Chandna (2010), Ebrahimnezhad et al. (2010), Eren (2010), Gong et al. (2010), Hatami et al. (2010), Sun (2010), Fernandes and Carmo-Silva (2010), Gharbi et al. (2010), Mirabi (2011), Gupta et al. (2011), Kaweegitbundit (2011), Sharma (2011) and Mehravaran and Logendran (2012).

We also found 20 papers that addressed the FS-SD-batch problem: Vakharia et al. (1995), Jordan (1996), Hwang and Sun (1997), Schaller et al. (1997, 2000), Cho and Ahn (2003), Reddy and Narendran (2003), França et al. (2005), Logendran et al. (2006), Hendizadeh et al. (2008), Yang et al. (2008), Ben-Dati et al. (2009), Lin et al. (2009), Mohammadi et al. (2010), Salmasi et al. (2010), Bouabda et al. (2011), Cheng and Ying (2011), Lin et al. (2011), Mohammadi and Fatemi Ghomi (2011) and Pan and Ruiz (2012). Tables 1 and 2 summarise the main features of both classes.

Table 1 Papers that address the FS-SD-job problem

References	*Approach method*	*Objective function*	*Criterion*	*Additional constraints*
Gupta (1969)	Optimal solution	Mono-criteria	C_{max}	-
Corwin and Esogbue (1974)	Optimal solution	Mono-criteria	C_{max}	Setup is performed in a single server
Uskup and Smith (1975)	Optimal solution	Mono-criteria	TSC	Delivery dates
Gupta (1975)	Optimal solution	Mono-criteria	TCO	-
Bellman et al. (1982)	Optimal solution	Mono-criteria	C_{max}	Setup is performed in a single server
Rothblum (1983)	Optimal solution	Mono-criteria	C_{max}	-
Gupta and Darrow (1985)	Heuristic	Mono-criteria	C_{max}	-
Gupta (1986)	Optimal solution	Mono-criteria	C_{max}	-
Gupta and Darrow (1986)	Heuristic	Mono-criteria	C_{max}	-
Srikar and Ghosh (1986)	Optimal solution	Bi-criteria	C_{max}; $\sum C_j$	-
Szwarc and Gupta (1987)	Optimal solution heuristic	Mono-criteria	C_{max}	Additive setup
Rajagoplan and Karimi (1987)	Heuristic	Mono-criteria	C_{max}	Transfer time Stock policies
Simons (1992)	Heuristic	Mono-criteria	C_{max}	-
Vob (1993)	Heuristic	Mono-criteria	C_{max}	Multiple machines in the second stage
Bolat (1994)	Optimal solution heuristic	Mono-criteria	TSC	-
Boltat et al. (1994)	Optimal solution heuristic	Mono-criteria	TCU	-
Gupta et al. (1995)	Optimal solution	Mono-criteria	C_{max}	-
Das et al. (1995)	Heuristic	Mono-criteria	C_{max}	-
Rios-Mercado and Bard (1996)	Optimal solution	Mono-criteria	C_{max}	-
Rajendran and Ziegler (1997)	Heuristic	Mono-criteria	$\sum w_j F_j$	-
Parthasarathy and Rajendran (1997a)	Metaheuristic	Mono-criteria	$\sum w_j T_j$	-
Parthasarathy and Rajendran (1997b)	Metaheuristic	Mono-criteria	$\max w_j T_j$	-
Rios-Mercado and Bard (1998a)	Heuristic metaheuristic	Mono-criteria	C_{max}	-
Rios-Mercado and Bard (1998b)	Optimal solution	Mono-criteria	C_{max}	-

Comment [t1]: Author: Please confirm if this reference citation pertains to both 'Rajendran and Ziegler (1997a) and (1997b)'. Reference entry:

Rajendran, C. and Ziegler, H. (1997a) 'Heuristics for scheduling in a flowshop with setup, processing, and removal times separated', *Production Planning and Control*, Vol. 8, No. 6, pp.568–576.

Rajendran, C. and Ziegler, H. (1997b) 'A heuristic for scheduling to minimize the sum of weighted flowtime of jobs in a flowshop with sequence-dependent setup times of jobs', *Computers and Industrial Engineering*, Vol. 33, No. 2, pp.281–284.

Table 1 Papers that address the FS-SD-job problem (continued)

References	*Approach method*	*Objective function*	*Criterion*	*Additional constraints*
Hwang and Sun (1998)	Metaheuristic	Mono-criteria	C_{max}	Precedence constraints
Sonmez and Baykasoglu (1998)	Optimal solution	Mono-criteria	$\Sigma w_j T_j$	-
Rios-Mercado and Bard (1999a)	Optimal solution	Mono-criteria	C_{max}	-
Rios-Mercado and Bard (1999b)	Heuristic	Mono-criteria	C_{max}	-
Normam (1999)	Metaheuristic	Mono-criteria	C_{max}	Limited buffer blocking
Demirkol and Uzsoy (2000)	Metaheuristic	Mono-criteria	L_{max}	Reentrant flow
Sun and Hwang (2001)	Optimal solution metaheuristic	Mono-criteria	C_{max}	Setup only on the second machine without stopping to setup
Rajendran and Ziegler (2003)	Heuristic	Bi-criteria	$\sum w_j F_j$; $\sum w_j T_j$	-
Rios-Mercado and Bard (2003)	Optimal solution	Mono-criteria	C_{max}	-
Maddux and Gupta (2003)	Heuristic	Mono-criteria	C_{max}	No buffer
Andrés et al. (2005)	Metaheuristic	Bi-criteria	C_{max}; $\sum T_j$	Precedence constraints
Ruiz et al. (2005)	Metaheuristic	Mono-criteria	C_{max}	-
Gajpal et al. (2005)	Metaheuristic	Mono-criteria	C_{max}	-
Tseng et al. (2006)	Heuristic	Mono-criteria	C_{max}	-
Huang and Yang (2008)	Heuristic Metaheuristic	Multi-criteria	TIT; IC; $\sum T_j$	Overlapping jobs Release dates Idle machines
Lo et al. (2008)	Optimal solution heuristic Metaheuristic	Mono-criteria	C_{max}	-
Mansouri et al. (2008)	Optimal solution heuristic Metaheuristic	Bi-criteria	C_{max}; $\sum S_j$	-
Ruiz and Stützle (2008)	Metaheuristic	Bi-criteria	C_{max}; $\sum w_j T_j/n$	-
Sajadi et al. (2008)	Optimal solution	Mono-criteria	$\sum w_i T_j$; C_{max}	Release dates Lag times
Yang and Liu (2008)	Metaheuristic	Bi-criteria	C_{max}; T_{max}	-

Table 1 Papers that address the FS-SD-job problem (continued)

References	*Approach method*	*Objective function*	*Criterion*	*Additional constraints*
Zandieh et al. (2008)	Optimal solution heuristic Metaheuristic	Mono-criteria	C_{max}	-
Dhingra and Chandna (2009)	Heuristic Metaheuristic	Multi-criteria	$\sum T_j$; $\sum E_j$; C_{max}	Maximum resource utilization Delivery dates
Maboudian and Shafaei (2009)	Optimal solution	Mono-criteria	C_{max};T_{max}	Multiple machines in the first stage
Martin (2009)	Optimal solution heuristic Metaheuristic	Mono-criteria	C_{max}	Transfer lot
Dong et al. (2009)	Heuristic	Mono-criteria	C_{max}	-
Eddaly et al. (2009)	Heuristic Metaheuristic	Mono-criteria	C_{max}	-
Dhingra and Chandna (2010)	Metaheuristic	Multi-criteria	$\sum w_jT_j$; $\sum w_jE_j$; C_{max}	-
Ebrahimnezhad et al. (2010)	Optimal solution heuristic	Bi-criteria	$\Sigma F_j/n$; $\Sigma T_j/n$	Lower bound Assembly line Transport time
Eren (2010)	Optimal solution heuristic	Bi-criteria	C_{max}; $\sum w_jC_j$	-
Gong e al. (2010)	Heuristic	Mono-criteria	C_{max}	Shared setup Blocking
Hatami et al. (2010)	Metaheuristic	Bi-criteria	ΣC_j ; $\Sigma F_j/n$	Assembly line Transfer time
Sun (2010)	Optimal solution	Mono-criteria	$\sum Fj$	Precedence constraints
Fernandes and Carmo-Silva (2010)	Heuristic	Multi-criteria	$\sum S_j$; TSC; IC	Decision job allocation
Gharbi et al. (2010)	Heuristic	Mono-criteria	$\sum C_j$	-
Mirabi (2011)	Optimal solution heuristic	Mono-criteria	C_{max}	-
Gupta et al. (2011)	Heuristic	Mono-criteria	RC	Idle/waiting time operator
Kaweegitbundit (2011)	Metaheuristic	Mono-criteria	C_{max}	-
Sharma (2011)	Heuristic	Mono-criteria	$C_{max;}$ $\Sigma w_jF_j/n$	Transport time Break machines
Mehravaran and Logendran (2012)	Optimal solution Metaheuristic	Bi-criteria	WIP; LS	Supply chain

Table 2 Papers that address the FS-SD-batch problem

References	*Approach method*	*Objective function*	*Criterion*	*Additional constraints*
Vakharia et al. (1995)	Heuristic	Mono-criteria	C_{max}	-
Jordan (1996)	Metaheuristic	Bi-criteria	$\sum w_jE_j$; $\sum w_jT_j$	Splitting lots
Hwang and Sun (1997)	Optimal solution	Mono-criteria	C_{max}	-
Schaller et al. (1997)	Heuristic	Mono-criteria	C_{max}	-
Schaller et al. (2000)	Heuristic	Mono-criteria	C_{max}	-
Cho and Ahn (2003)	Metaheuristic	Mono-criteria	$\sum T_j$	-
Reddy and Narendran (2003)	Heuristic	Bi-criteria	$\sum T_j$; $\sum U_j$	Cellular manufacturing
França et al. (2005)	Metaheuristic	Mono-criteria	C_{max}	-
Logendran et al. (2006)	Optimal solution metaheuristic	Mono-criteria	C_{max}	-
Hendizadeh et al. (2008)	Metaheuristic	Mono-criteria	C_{max}	Cellular manufacturing
Yang et al. (2008)	Optimal solution	Mono-criteria	C_{max}	Reentrant flow
Ben-Dati et al. (2009)	Optimal solution	Mono-criteria	C_{max}	Dependent machines
Lin et al. (2009)	Heuristic metaheuristic	Bi-criteria	C_{max}; $\sum T_j$	-
Mohammadi et al. (2010)	Optimal solution Heuristic	Mono-criteria	$\sum S_j$	Lot size Concurrent programming Planning horizon
Salmasi et al. (2010)	Optimal solution metaheuristic	Mono-criteria	$\sum F_j$	-
Bouabda et al. (2011)	Optimal solution metaheuristic	Mono-criteria	C_{max}	Cellular manufacturing
Cheng and Ying (2011)	Heuristic	Mono-criteria	C_{max}	Cellular manufacturing
Lin et al. (2011)	Metaheuristic	Mono-criteria	Cmax	Cellular manufacturing
Mohammadi and Fatemi Ghomi (2011)	Metaheuristic	Multi-criteria	TSC; IC; PC	Planning horizon
Pan and Ruiz (2012)	Heuristic	Mono-criteria	C_{max}	-

5 Analysis

5.1 Evolution of the number of published papers

Using a lexicographic search procedure, Gupta (1969, 1975) developed a pioneering procedure for solving the production scheduling problem in FS-SD-job. For a flow shop with two machines, Corwin and Esogbue (1974) proposed the first dynamic programming procedure for obtaining the optimal solution, while Gupta and Darrow (1985, 1986) presented the first heuristic methods for a two-machine environment.

Since the first work that addressed the FS-SD problem in the late 1960s, research interest has progressively increased in the following decades.

Methods to address the FS-SD problem were found in 83 articles. Figure 1 illustrates the proportions of methods for the FS-SD-job and FS-SD-batch, and Figure 2 shows the temporal evolution of the number of papers published.

Figure 1 Percentage of papers that address job setups and batch setups (FS-SD) (see online version for colours)

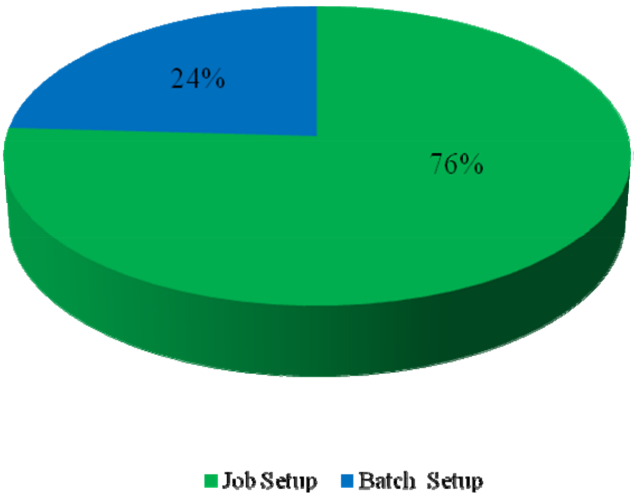
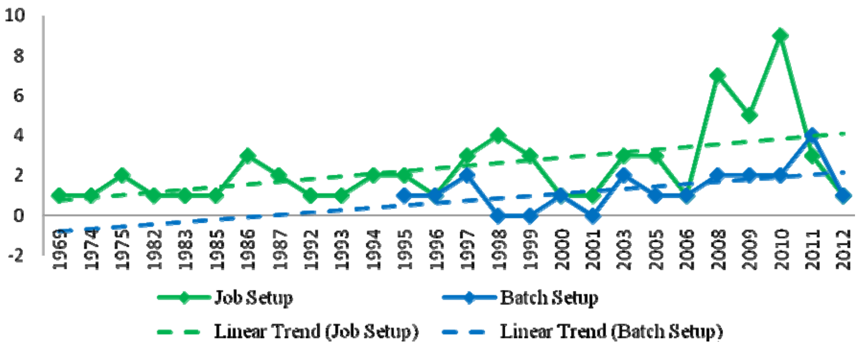


Figure 2 Evolution of the number of papers published (see online version for colours)



Approximately 76% of the papers address the FS-SD-job problem. The FS-SD-batch problem is less studied, but the first paper on this subject is much more recent.

The evolution of FS-SD-job studies is more highly expressed in the 1990s and 2000s; the number of published studies increased by 41.17% in the 2000s from the number of publications in the 1990s. The trend line throughout the entire period indicates growth in the number of publications. One can thus conclude that the subject has been of interest to the academic community since the 1970s and remains a pressing issue, as verified by the number of publications in the beginning of the 2010s.

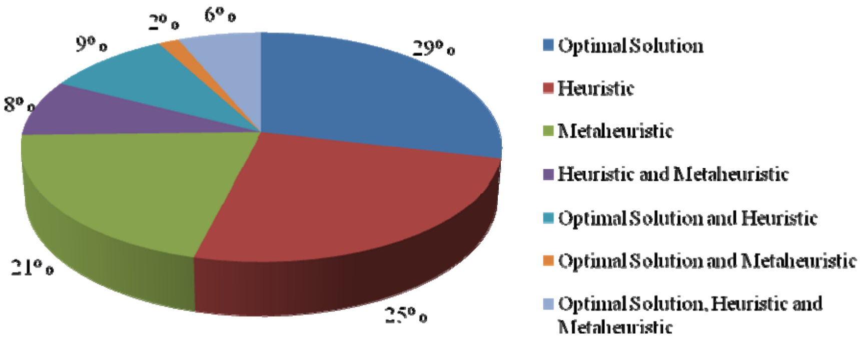
The first work to address the FS-SD-batch problem was published in the mid-1990s. The FS-SD-batch literature analyses show that the number of published studies increased by 125% in the 2000s from those published in the 1990s. The trend line indicates growth in this field of research for years to come, as verified by the number of publications in the beginning of the 2010s.

In both cases, FS-SD-job and FS-SD-batch, the growth pattern occurs because actual manufacturing environments are increasingly pressured to produce a large variety of products, which leads to the need for setups and production batches.

5.2 *Approaches for developing solution methods*

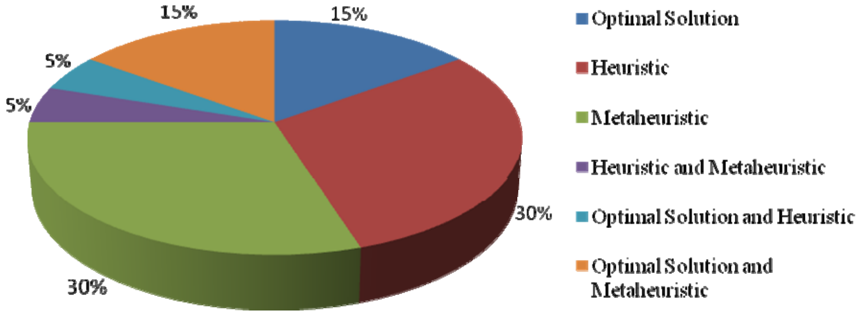
Of the 63 papers addressing FS-SD-job problems, 29 (46.03%) adopted the approach of the optimal solution, 31 (49.2%) used a heuristic approach, and 23 (36.5%) adopted a metaheuristic approach. Because most papers adopt more than one approach, i.e., use more than one method to solve the problem, 74.6% of the works (47 papers) adopted a single approach, 19.04% (12 papers) two approaches, and 6.34% (4 papers) three approaches. Figure 3 illustrates these findings.

Figure 3 Approaches used in the FS-SD-job literature (see online version for colours)



In the FS-SD-batch literature, 7 of the 20 works (35%) used the optimal solution approach, 8 works (40%) adopted a heuristic approach and 10 works (50%) used a metaheuristic approach. In fact, 75% of the works (15 papers) adopt only one of the three approaches, and 25% (5 papers) use two approaches. Figure 4 illustrates these findings.

Figure 4 The approaches used to solve the FS-SD-batch problem (see online version for colours)



5.3 *Types of function and objective-optimisation criteria adopted*

In the FS-SD-job literature, 77.77% (49 works) develop solution methods with a mono-criteria objective function, 15.87% (10 studies) develop a bi-criteria objective function method and only 6.34% (4 studies) develop a multi-criteria objective function method.

Among the FS-SD-job mono-criteria studies, 75.51% of the studies adopt the makespan (C_{max}) as a performance criterion. The total weighted tardiness (Σw_jT_j) appears in 6.12% of the studies, and TSC is adopted in 4.08%. The total completion time (ΣCj), maximum weighted tardiness ($maxw_jT_j$), maximum tardiness (T_{max}), maximum lateness (L_{max}), total flow time (ΣF_j), total weighted flow time (Σw_jF_j), mean weighted flow time ($\Sigma w_jF_j/n$), total cost of opportunity (TCO), total cost utility (TCU) and rental cost (RC) appear in the objective functions at 2.32% each (1 study).

In the FS-SD-job bi-criteria papers, five papers (50% of the studies) adopt the makespan (C_{max}). Other criteria adopted in the bi-criteria papers for FS-SD-job include total completion time (ΣC_j), total weighted completion time (Σw_jC_j), mean time flow ($\Sigma F_j/n$), total weighted flow time (Σw_jF_j), mean tardiness ($\Sigma T_j/n$), total weighted tardiness (Σw_jT_j), weighted mean tardiness ($\Sigma w_jT_j/n$), maximum tardiness (T_{max}), total setup time (ΣS_j), reduction of work in process (WIP) and LS.

In the FS-SD-job multi-criteria papers, makespan (C_{max}), total tardiness (ΣT_j) and IC appear in two papers (50% of studies). Only one paper adopts total weighted tardiness (Σw_jT_j), total earliness (ΣE_j), weighted total earliness (Σw_jE_j), total setup costs (TSC), total setup time (ΣS_j) and TIT.

Among the FS-SD-batch literature, 80% (16 papers) develop solution methods with mono-criteria objective functions, 15% (3 studies) develop methods with a bi-criteria objective function and 5% (1 study) develop multi-criteria objective function methods. In mono-criteria studies, the makespan (C_{max}) is adopted as a performance criterion in 81.25% of the studies (13 studies). The total tardiness (ΣT_j), total time flow (ΣF_j) and total setup time (ΣS_j) are present in 6.25% of the studies (1 study for each criterion). To illustrate handling bi-criteria objective functions, we highlight the total tardiness (ΣT_j), which was identified in two studies. Performance criteria, i.e., makespan (C_{max}), weighted total earliness (Σw_jE_j), weighted total tardiness (Σw_jT_j) and number of late jobs (ΣU_j), also appear in one study each. In the only multi-criteria function study, the criteria used in the objective function were TSC, IC and PC.

5.4 Additional constraints considered

Of the studies that address FS-SD-job problems, 39.68% (25 of 63 works) have some additional constraint. Precedence constraints are present in 12% of the studies. Delivery dates, release dates, setup performed in a single server, transport time, transfer time, blocking and assembly line also appear in the literature, i.e., each constraint appears in 8% of the studies. The additional constraints of break machines, multiple machines in the first stage, multiple machines in the second stage, reentrant flow, additive setup, setup only performed in the second machine, without stopping to setup, shared setup, overlapping jobs, no buffer, decision job allocation, stock policies, maximum resource utilisation, idle machines, lower bound, transfer lot, idle/waiting time operator and supply chain also appear in studies, but they appear less frequently, i.e., each constraint appears in 4% of the studies. This analysis found several studies that used more than one additional restriction.

In the FS-SD-batch literature, 50% of the studies (10 of the 20 jobs) have some type of additional constraint. Cellular manufacturing is present in 50% of the studies, and planning horizon was observed in 20% of the studies. The additional constraints of splitting lots, reentrant flow, dependent machines, lot size and concurrent programming also appear in the literature, but they do so less frequently, i.e., each constraint appears in 10% of the studies. This analysis verified that only the Mohammadi et al. (2010) study used more than one type of additional restriction.

6 Conclusions

This article reviews the literature published between 1969 and 2012 (83 articles) on flow shop production scheduling with sequence-dependent setup times required for processing jobs or batches. The literature was classified into two broad categories: flow shop with setup times dependent on the job sequence (FS-SD-job) and flow shop with setup times dependent on the batch sequence (FS-SD-batch).

The studies were analysed based on the following:

a the number of publications and recent research development

b the approach used to develop solution methods (optimal solution, heuristic and meta-heuristic)

c the type of objective function (mono-, bi- or multi-criteria)

d the performance criteria and restrictions adopted in the model considered.

The survey results show that the number of papers that developed solutions for the FS-SD-job problem has grown since the 1960s, as has the number of studies that handle the FS-SD-batch problem since the mid-1990s. This trend is linked to the current competitive environment, which increasingly demands a variety of products and services. This area thus seems to represent an excellent area for further research.

The results also shows that the most common type of approach used to solve to the problems considered for FS-SD-job is the heuristic, and that for the FS-SD-batch is the metaheuristic. Papers addressing the FS-SD-Job problem have also used the optimal solution approach, and metaheuristics represent the least-used approach. Papers addressing the FS-SD-Batch problem have also used the heuristic approach, and the optimal solution approach represents the least-used method. Though few studies have used more than one approach to develop solution methods, future studies can use more than one approach.

Most papers considering both FS-SD-Job and FS-SD-Batch use mono-criteria objective functions. The mono-criteria objective functions with makespan (C_{max}) performance criteria have been widely used to develop mono-criteria solution methods in both cases. Minimising the makespan may be relevant in several cases because it optimises using limited resources. However, other objectives are also important in practice.

Few studies have investigated the scheduling problem with bi- and multi-criteria functions in the literature. For both cases, FS-SD-job and FS-SD-batch, most works were associated with the makespan criteria related to job delay. Future research in production scheduling problems can focus on this aspect, which already appears to be a trend in production scheduling.

Few papers include additional restrictions. For FS-SD-job problems, the additional constraints involving precedence constraints, delivery dates, release dates, setup performed in a single server, transport time, transfer time, blocking and assembly line are more prevalent. For FS-SD-batch problems, the most common additional restrictions are cellular manufacturing and planning horizon. Many real additional restrictions were not investigated and thus represent opportunity for future research.

The unique contributions of this paper is to perform an extensive literature review on FS-SD problem, providing researchers and practical production managers with a broad overview of the topic. In addition some directions for future research arise from this study, as follows:

- the FS-SD problem appears to be a very promising area for future research, once it represent a lot of manufacturing environment seldom found in practice
- using combination of different solution approaches to solve the FS-SD problem also appears to be a modern tendency
- future research related to FS-SD problem may be more focused on performance measures related to the flow time (mean flow time and total flow time) and due dates (lateness and tardiness), which are desirable in today's competitive environment
- multi-criteria objective functions has had little attention on the literature
- a lot of additional restrictions can be included in order to make the FS-SD more real. Therefore, the probability of such model be implemented in practice may arise.

The limitations of the present study is to focus only in sequence-dependent set up time. There are a lot of other studies that consider sequence-independent set up times that were not considered in this study and represent an opportunity for future studies.

References

Allahverdi, A. and Soroush, H.M. (2008) 'The significance of reducing setup times/setup costs', *European Journal of Operational Research*, Vol. 187, No. 3, pp.978–984.

Allahverdi, A., Cheng, T.C.E. and Kovalyov, M.Y. (2008) 'A survey of scheduling problems with setup times or costs', *European Journal of Operational Research*, Vol. 187, No. 3, pp.985–1032.

Allahverdi, A., Gupta, J.N.D. and Aldowaisan, T. (1999) 'A review of scheduling research involving setup considerations', *Omega – The International Journal of Management Science*, Vol. 27, No. 2, pp.219–239l.

Andrés, C., Tomaás, J.V., Garcia-Sabater, J.P. and Miralles, C. (2005) 'A multi-objective genetic algorithm to solve the scheduling problem in flowshops with sequence dependent setup times', in *Proceedings of the International Conference on Industrial Engineering and Systems Management*, Marrakech, Morocco, pp.630–635.

Bellman, R., Esogbue, A.O. and Nabeshima, I. (1982) *Mathematical Aspects of Scheduling with Sequence-dependent Setup Times and Release Dates*, New York, Pergamon Press.

Ben-Dati, L., Mosheiov, B. and Oron, D. (2009) 'Batch scheduling on two-machine flowshop with machine-dependent setup times', *Advances in Operations Research*, pp.1–10

Bolat, A. (1994) 'Sequencing jobs on a automobile assembly line: objectives and procedures', *International Journal of Production Research*, Vol. 32, No. 5, pp.1219–1236.

Bolat, S., Savsar, M. and Al-Fawzan, M.A. (1994) 'Algorithms for real-time scheduling of jobs on mixed model assembly lines', *Computers & Operations Research*, Vol. 21, No. 5, pp.487–498.

Bouabda, R., Jarboui, B., Eddaly, M. and Rebai, A. (2011) 'A branch and bound enhanced genetic algorithm for scheduling a flowline manufacturing cell with sequence dependent family setup times', *Computers & Operations Research*, Vol. 38, No. 1, pp.287–393.

Bryman, A. (1989) *Research Methods and Organization Studies*, London, Uniwin Hyman.

Burtseva, L., Yaurima, V. and Parra, R.R. (2010) *Scheduling Methods for Hybrid Flow Shops with Setup Times*, in *Handbook Future Manufacturing Systems*, India, InTech.

Cheng, H-M. and Ying, K-C. (2011) 'Minimizing makespan in a flow-line manufacturing cell with sequence dependent family setup times', *Expert Systems with Applications*, Vol. 38, No. 12, pp.15517–15522.

Cheng, T.C.E., Gupta, J.N.D. and Wang, G. (2000) 'A review of flowshop scheduling research with setup times', *Production and Operations Management*, Vol. 9, No. 3, pp.262–282.

Cho, K.K. and Ahn, B.H. (2003) 'A hybrid genetic algorithm for group scheduling with sequence dependent group setup time', *International Journal of Industrial Engineering: Theory Applications and Practice*, Vol. 10, pp.442–448.

Corwin, B.D. and Esogbue, A.O. (1974) 'Two-machine flowshop scheduling problems with sequence dependent setup times: a dynamic programming approach', *Naval Research Logistics Quarterly*, Vol. 21, No. 3, pp.515–524.

Das, S.R., Gupta, J.N.D. and Khumawala, B.M.A. (1995) 'Savings index heuristic algorithm for flowshop scheduling with sequence dependent set-up times', *Journal of the Operational Research Society*, Vol. 46, No. 11, pp.1365–1373.

Demirkol, E. and Uzsoy, R. (2000) 'Decomposition methods for reentrant flow shops with sequence-dependent setup times', *Journal of Scheduling*, Vol. 3, No. 3, pp.155–177.

Dhingra, A. and Chandna, P. (2009) 'Hybrid genetic algorithm for multicriteria scheduling with sequence dependent set up time', *International Journal of Engineering*, Vol. 3, No. 5, pp.510–520.

Dhingra, A. and Chandna, P. (2010) 'Multi-objective flow shop scheduling using hybrid simulated annealing', *Measuring Business Excellence*, Vol. 14, No. 3, pp.30–41.

Dong, X., Huang, H. and Chen, P. (2009) 'Study on heuristics for the permutation flowshop with sequence dependent setup times', *International Conference on Information Reuse & Integration*, pp.417–421.

Ebrahimnezhad, S.A., Tavakoli, M.R., Hatami S. and Maboudian, Y. (2010) 'An assembly flow-shop scheduling problem with sequence-dependent setup and transportation times', *International Journal of Industrial Engineering and Production Management*, Vol. 2, No. 1, pp.15–23.

Eddaly, M., Jarboul, B., Bouabda, R. and Rebai, A. (2009) 'Hybrid estimation of distribution algorithm for permutation flowshop scheduling problem with sequence dependent family setup times', *Computers and Industrial Engineering*, Vol. 3, Nos. 6–9, pp.357–363.

Eren, T. (2010) 'A bicriteria m-machine flowshop scheduling with sequence-dependent setup times', *Applied Mathematical Modelling*, Vol. 34, No. 2, pp.284–293.

Fernades, N.O. and Carmo-Silva, S. (2010) 'Order release in a workload controlled flow-shop with sequence-dependent set-up times', *International Journal of Production Research*, Vol. 49, No. 8, pp.2443–2454.

Fernandes, F.C.F.,Azeka, F., Barreto, M.C.M. and Godinho Filho, M. (2009) 'Identifying production planning and control top authors: analysis of a survey', *International Journal of Business Innovation and Research*, Vol. 3, No. 5, pp.461–478.

França, P.M., Gupta, J.N.D., Mendes, A., Moscato, P. and Veltink, K.J. (2005) 'Evolutionary algorithms for scheduling a flowshop manufacturing cell with sequence dependent family setups', *Computers and Industrial Engineering*, Vol. 48, No. 3, pp.491–506.

French, S. (1982) *Sequencing and Scheduling: An Introduction to the Mathematics of the Job Shop*, New York, Wiley.

Gajpal, Y., Rajendran, C. and Ziegler, H. (2005) 'An ant colony algorithm for scheduling in flowshops with sequence-dependent setup times of jobs', *International Journal of Manufacturing Technology*, Vol. 30, Nos. 5–6, pp.416–424.

Gharbi, A., Ladhari, T., Mskani, M.K. and Serairi, M. (2010) 'Polynomial lower bounds for the two-machine flowshop problem with sequence-independent setup times', *Electronic Notes in Discrete Mathematics*, Vol. 36, No. 1, pp.1089–1096.

Gomes, C. F., Yasin, M.M. and Lisboa, J.V. (2007) 'The measurement of operational performance effectiveness: an innovative organizational approach', *International Journal of Business Innovation and Research*, Vol. 1, No. 4, pp.337–364.

Gong, H., Tang, L. and Duin, C.W. (2010) 'A two-stage flow shop scheduling problem on a batching machine and a discrete machine with blocking and shared setup times', *Computers & Operations Research*, Vol. 37, No. 5, pp.960–969.

Gupta, D., Singh, H., Rattan, J. and Kaur, H. (2011) 'Application of idle/waiting time operator $o_{i,w}$ of an equivalent job for a job block criteria for minimization of rental cost in two stage flow shop scheduling problem, in which setup time separated from processing time and each associated with probabilities', *International Journal of Engineering Science and Technology*, Vol. 10, No. 10, pp.7504–7524.

Gupta, J.N.D. (1969) 'Economic aspects of scheduling theory', PhD dissertation, Texas Tech University, Lubbock, Texas.

Gupta, J.N.D. (1986) 'Flow shop schedules with sequence dependent setup times', *Journal of Operational Research Society Japanese*, Vol. 29, pp.206–219.

Gupta, J.N.D. (1975) 'A search algorithm for the generalized scheduling problem', *Computers & Operations Research*, Vol. 2, No. 2, pp.83–90.

Gupta, J.N.D. and Darrow, W.P. (1985) 'Approximate schedules for the two-machine flow-shop with sequence dependent setup times', *Indian Journal of Management and Systems*, Vol. 1, pp.6–11.

Gupta, J.N.D. and Darrow, W.P. (1986) 'The two-machine sequence dependent flowshop scheduling problem', *European Journal of Operational Research*, Vol. 24, No. 3, pp.439–446.

Gupta, J.N.D. and Stafford, Jr., E.F. (2006) 'Flow shop scheduling research after five decades', *European Journal of Operational Research*, Vol. 169, No. 3, pp.699–711.

Gupta, J.N.D., Das, S.R. and Gosh, S. (1995) 'Flowshop scheduling with sequence dependent setup times', Working paper, IN 47306, Departament of Management – Ball State University, Munice.

Hatami, S., Ebrahimnejad, S., Tavakkoli-Moghaddam, R. and Maboudian, Y. (2010) 'Two meta-heuristics for three-stage assembly flowshop scheduling with sequence-dependent setup times', *The International Journal of Advanced Manufacturing Technology*, Vol. 50, Nos. 9–10, pp.1153–1164.

Hendizadeh, S.H. (2008) 'Meta-heuristics for scheduling a flowline manufacturing cell with sequence dependent family setup times', *International Journal of Production Economics*, Vol. 111, No. 2, pp.593–605.

Huang, R-H. and Yang, C-L. (2008) 'Solving a multi-objective overlapping flow-shop scheduling', *The International Journal of Advanced Manufacturing Technology*, Vol. 42, Nos. 9–10, pp.955–962.

Hwang, H. and Sun, J.U. (1997) 'Production sequencing with reentrant work flows and sequence dependent setup times', *Computers and Industrial Engineering*, Vol. 33, No. 9, pp.773–776.

Hwang, H. and Sun, J.U. (1998) 'Production sequencing problem with re-entrant work flows and sequence dependent setup times', *International Journal of Production Research*, Vol. 36, No. 9, pp.2435–2450.

Johnson S.M. and Montgomery D.C. (1974) *Operations Research in Production, Planning, Scheduling and Inventory Control*, New York: Wiley.

Jordan, C. (1996) *Batching and Scheduling: Models and Methods for Several Problem Classes*, Springer, Berlin, Germany.

Kaweegitbundit, P. (2011) 'Comparison of heuristic for flow shop scheduling problems with sequence dependent setup time', *Advanced Materials Research*, Vol. 339, pp.332–335.

Lin, S-W., Gupta, J.N.D., Ying, K-C. and Lee, Z-J. (2009) 'Using simulated annealing to schedule a flowshop manufacturing cell with sequence-dependent family setup times', *International Journal of Production Research*, Vol. 47, No. 12, pp.3205–3217.

Lin, S-W., Ying, K-C., Lu, C-C. and Gupta, J.N.D. (2011) 'Applying multi-start simulated annealing to schedule a flowline manufacturing cell with sequence dependent family setup times', *International Journal of Production Economics*, Vol. 130, No. 2, pp.246–254.

Lo, M-C., Chen, J-S. and Chang, Y-F. (2008) 'Two-machine flexible flow-shop scheduling with setup times', *Journal of Applied Sciences*, Vol. 8, No. 12, pp.2217–2225.

Logendran, R., Salmasi, N. and Sriskandarajah, C. (2006) 'Two machine group scheduling problems in discrete parts manufacturing with sequence-dependent setups', *Computers and Operations Research*, Vol. 33, No. 1, pp.158–180.

Maboudian, Y. and Shafaei, R. (2009) 'Modeling a bi-criteria two stage assembly flow shop scheduling problem with sequence dependent setup times', *Industrial Engineering and Engineering Management*, Vol. 8-11, pp.1748–1752.

MacCarthy, B.L. and Liu, J.Y. (1993) 'Addressing the gap in scheduling research: a review of optimization and heuristic methods in production scheduling', *International Journal of Production Research*, Vol. 31, No. 1, pp.59–79.

Maddux III, H. S. and Gupata, J.N.D. (2003) 'Scheduling intermediate and finished products in a two-stage flowshop with sequence-dependent setup times', *Annual meeting of the Decision Sciences Institute*, Vol. 34, pp.15779–1585.

Malinin, L. (2010) 'The method for transforming a business goal into a set of engineering problems', *International Journal of Business Innovation and Research*, Vol. 4, No. 4, pp.321–337.

Mansouri, S.A., Hendizadeh, S.H. and Salmasi, N. (2008) 'Bicriteria scheduling of a two-machine flowshop with sequence-dependent setup times', *The International Journal of Advanced Manufacturing Technology*, Vol. 40, Nos. 11–12, pp.1216–1226.

Martin, C.H. (2009) 'A hybrid genetic algorithm/mathematical programming approach to the multi-family flowshop scheduling problem with lot streaming', *Omega*, Vol. 37, No. 1, pp.126–137.

Martins, R.A. (2010) 'Abordagens quantitativa e qualitativa', in Miguel, P.A.C. (Ed.): *Metodologia de Pesquisa em Engenharia de Produção e Gestão de Operações*, Elsevier, Rio de Janeiro.

Mehravaran, Y. and Longendran, R. (2012) 'Non-permutation flowshop scheduling in a suppy chain with sequence-dependent setu times', *International Journal of Production Economics*, Vol. 135, No. 2, pp.953–963.

Mirabi, M. (2011) 'Ant colony optimization technique for the sequence-dependent flowshop scheduling problem', *The International Journal of Advanced Manufacturing Technology*, July, Vol. 55, Nos. 1–4, pp.317–326.

Mohammadi, M, Torabi, S.A., Fatemi-Ghomi, S.M.T. and Karimi, B. (2010) 'A new algorithmic approach for capacitated lot-sizing problem in flow shops with sequence dependent setups', *The International Journal of Advanced Manufacturing Technology*, Vol. 49, Nos. 1–4, pp.201–211.

Mohammadi, M. and Fatemi Ghomi, S.M.T. (2011) 'Genetic algorithm-based heuristic for capacitated lotsizing problem in flow shops with sequence-dependent setups', *Expert Systems Applied*, Vol. 38, No. 6, pp.7201–7207.

Norman, B.A. (1999) 'Scheduling flowshops with finite buffers and sequence-dependent setup times', *Computers and Industrial Engineering*, Vol. 36, No. 1, pp.163–177.

Pan, Q. and Ruiz, R. (2012) 'An estimation of distribution algorithm for lot-streaming flow shop problems with setup times', *Omega*, Vol. 40, No. 2, pp.166–180.

Parthasarathy, S. and Rajendran, C. (1997a) 'A simullated annealing heuristic for scheduling to minimize mean weighted tardiness in a flowshop with sequence dependent setup times of jobs – a case study', *Production Planning & Control*, Vol. 8, No. 5, pp.475–483.

Parthasarathy, S. and Rajendran, C. (1997b) 'An experimental evaluation of heuristics for scheduling in a real-life flowshop with sequence-dependent setup times of job', *International Journal of Production Economics*, Vol. 49, No. 3, pp.255–263.

Pinedo, M. (2008) *Scheduling: Theory, Algorithms, and Systems*, Prentice-Hall, New Jersey.

Rajagopalan, D. and Karimi, I.A. (1987) 'Scheduling in serial mixed-storage multiproduct processes with transfer and set-up times', in Reklaitis, G.V. and Spriggs, H.D. (Eds.): *Foundations of Computer Aided Process Operations*, pp.679–686, Elsevier Science Publishers, New York.

Rajendran, C. and Ziegler, H. (1997a) 'Heuristics for scheduling in a flowshop with setup, processing, and removal times separated', *Production Planning and Control*, Vol. 8, No. 6, pp.568–576.

Rajendran, C. and Ziegler, H. (1997b) 'A heuristic for scheduling to minimize the sum of weighted flowtime of jobs in a flowshop with sequence-dependent setup times of jobs', *Computers and Industrial Engineering*, Vol. 33, No. 2, pp.281–284.

Rajendran, C. and Ziegler, H. (2003) 'Scheduling to minimize the sum o f weighted flowtime and weighted tardiness of Jobs in a flow shop with sequence-dependent setup times', *European Journal of Operational Research*, Vol. 3, No. 3, pp.513–522.

Reddy, V. and Narendran, T.T. (2003) 'Heuristics for scheduling sequence dependent set-up jobs in flow line cells', *International Journal of Production Research*, Vol. 41, No. 1, pp.193–206.

Rios-Mercado, R.Z. and Bard, J.F. (1996) 'The flowshop scheduling polyhedron with setup times', Technical Report ORP96-07, Graduate Program in Operations Research, University of Texas at Austin, Austin-TX.

Ríos-Mercado, R.Z. and Bard, J.F. (1998a) 'Heuristics for the flow line problem with setup costs', *European Journal of Operational Research*, Vol. 110, No. 1, pp.76–98.

Comment [t2]: Author: Please cite the reference in the text or delete from the list if not required.

Comment [t3]: Author: Please cite the reference in the text or delete from the list if not required.

Ríos-Mercado, R.Z. and Bard, J.F. (1998b) 'Computational experience with a branch-and-cut algorithm for flowshop scheduling with setups', *Computers & Operations Research*, Vol. 25, No. 5, pp.351–366.

Rios-Mercado, R.Z. and Bard, J.F. (1999a) 'A branch-and-bound algorithm for flowshop scheduling with setup times', *IEE Transactions*, Vol. 31, pp.721–731.

Rios-Mercado, R.Z. and Bard, J.F. (1999b) 'An enhanced TSP-based heuristic for makespan minimization in a flowshop with setup times', *Journal of Heuristics*, Vol. 5, No. 1, pp.53–70.

Rios-Mercado, R.Z. and Bard, J.F. (2003) 'The flowshop scheduling polyhedron with setup times', *Journal of Combinatorial Optimization*, Vol. 7, No. 3, pp.291–318.

Rothblum, U.G. (1983) 'A dynamic programming formulation of a production sequencing problem', *Computers and Industrial Engineering*, Vol. 7, No. 1, pp.69–75.

Ruiz, R. and Stützle, T. (2008) 'An iterated greedy heuristic for the sequence dependent setup times flowshop problem with makespan and weighted tardiness objectives', *European Journal of Operational Research*, Vol. 187, No. 3, pp.1143–1159.

Ruiz, R., Maroto, C. and Alcaraz, J. (2005) 'Solving the flowshop scheduling problem with sequence dependent setup times using advanced metaheuristics', *European Journal of Operation Research*, Vol. 165, No. 1, pp.34–54.

Sajadi, S.J., Aryanezhad, M.B. and Ziaee, M. (2008) 'The general flowshop scheduling: mathematical models', *Journal of Applied Sciences*, Vol. 8, No. 17, pp.3032–3037.

Salmasi, N., Longendran, R. and Skandari, M.R. (2010) 'Total flow time minimization in a flowshop sequence-dependent group scheduling problem', *Computers & Operations Research*, Vol. 37, No. 1, pp.199–212.

Schaller, J., Gupta, J.N.D. and Vakharia, A.J. (2000) 'Scheduling a flowline manufacturing cell with sequence dependent family setup times', *European Journal of Operational Research*, Vol. 125, No. 2, pp.324–339.

Schaller, J.E., Gupta, J.N.D. and Vakharia, A.J. (1997) 'Group scheduling with sequence dependent setups', Proceedings *of the Annual Decision Sciences Institute Meeting*, San Diego, CA, pp.1141–1143.

Sharma, S. (2011) 'Solving n-jobs, 3-machines constrained flow shop scheduling processing time, setup time each associated with probabilities including job-block criteria', *Journal of Energy Technologies and Policy*, online version, Vol. 1, No. 3, pp.22–35.

Simons, Jr., J.V. (1992) 'Heuristics in flow shop scheduling with sequence dependent setup times', *Omega*, Vol. 20, No. 2, pp.215–225.

Sonmez, A.I. and Baykasoglu, A. (1998) 'New dynamic programming formulation of (n · m) flowshop sequencing problems with due dates', *International Journal of Production Research*, Vol. 36, No. 8, pp.2269–2283.

Srikar, B.N. and Ghosh, S. (1986) 'A MILP model for the n-job, m-stage flowshop, with sequence dependent setup times', *International Journal of Production Research*, Vol. 24, No. 6, pp.1459–1472.

Sun, J.U. and Hwang, H. (2001) 'Scheduling problem in a twomachine flow line with the N-step prior-job-dependent set-up times', *International Journal of Systems Science*, Vol. 32, No. 3, pp.375–385.

Sun, U.J. (2010) 'Sequencing problem in a two machine flow shop with sequence dependent setup times', *The 2010 EABR and ETLC Conference*, Dublin, Ireland.

Szwarc, W. and Gupta, J.N.D. (1987) 'A flow-shop problem with sequence-dependent additive setup times', *Naval Research Logistics*, Vol. 34, No. 5, pp.619–627.

Talib, F., Rahman, Z. and Quresi, M.N. (2012) 'Total quality management in service sector: a literature review', *International Journal of Business Innovation and Research*, Vol. 6, No. 3, pp.259–301.

Tseng, F.T., Gupta, J.N.D. and Stafford, E.F. (2006) 'A penalty-based heuristic algorthim for the permutation flow shop scheduling problem with sequence-dependent setup times', *Journal of the Operational Research Society*, Vol. 57, No. 5, pp.541–551.

Urlings, T. (2010) 'Heuristics and metaheuristics for heavily constrained hybrid flow shop problems', Doctoral thesis, Universidad Politécnica de Valencia, Valencia.

Uskup, E. and Smith, S.B. (1975) 'A branch-and-bound algorithm for two-stage production-sequencing problems', *Operations Research*, Vol. 23, No. 1, pp.118–136.

Vakharia, A.J., Schaller, J.E. and Gupta, J.N.D. (1995) 'Designing and scheduling manufacturing cells', *Proceedings of the INFORMS National Meeting*, New Orleans.

Vob, S. (1993) 'The two-stage hybrid flow shop scheduling problem with sequence-dependent setup times', *Operations Research in Production Planning and Control*, Springer, Berlin, pp.336–352.

Yang, D-L., Kuo, W-H. and Chern, M.S. (2008) 'Multi-family scheduling in a two machine reentrant flow shop with setups', *European Journal of Operational Research*, Vol. 187, No. 3, pp.1160–1170.

Yang, K. and Liu, X. (2008) 'A bi-criteria optimization model and algorithm for scheduling in a real-world flow shop with setup times', *Intelligent Computation Technology and Automation*, Vol. 1, No. 1, pp.535–539.

Zacarelli, S.B. (1987) *Programação e Controle da Produção*, São Paulo, Pioneira.

Zandieh, M., Jolai, F., Fatemi Ghomi, S.M.T. and Mirabi, M. (2008) 'Hybrid electromagnetism-like algorithm for the flowshop scheduling with sequence-dependent setup times', *Journal of Applied Sciences*, Vol. 8, No. 20, pp.3621–3629.