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Flowshop scheduling problems with due date related objectives: A review of the literature*

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1. Introduction

In this work we analyse the scheduling literature regarding flowshop with due date related objectives. The importance of this topic is reflected in the wide existing literature. One of the first works on this topic is undertaken by Jackson (1955), and it is considered the starting point of the research about scheduling considering due dates (Gordon et al., 2002). In general, there exist some reviews about problems related with due date as Baker and Scudder (1990), Keskinocak and Tayur (2004), Koulamas (1994), Sen and Gupta (1984). The special case of due date assignment problems can be consulted in Cheng and Gupta (1989), Gordon et al (2002), Lee (2003), Gordon et al (2004), Kaminsky and Hochbaum (2004) and Minella et al (2008).

To the best of our knowledge, none of them tackled specifically the flowshop problem with due date related objectives and only some of these reviews include references related to this layout. However, there are a high number of references related to the flowshop layout, we review them in this work, including those references from the reviews previously cited. In total, we have reviewed a number of papers related with the topic, excluding references considering batches, fuzzy, hybrid or modifiable flowshops. The literature has been classified according to the case in which the due date is a given parameter (analysed in Section 2), or it is a variable to be determined (studied in Section 3). A table for each case with the references analysed is presented, indicating the problems analysed, the solution methods that have been employed (i.e. approximate or exact methods), and the algorithms employed to solve them and some comments.

2. Flowshop scheduling problems with given due dates

Production processes consider penalties associated with jobs completed early or late (Birman and Mosheiov, 2004). These penalties can be calculated when due dates are a given parameter, which is established by certain job- and workload-related parameters (Ízdamar and Yazgaç, 1997), but not according to a schedule which is a future decision considering objectives related to earliness/tardiness. This case has been widely studied in the flowshop setting.

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Since there are a great number of references, they have been classified according to the objective studied: Maximum Lateness (L_{max}) problems are shown in Table 1, Maximum Tardiness and Maximum Weighted Tardiness (T_{max} and T_{max}^{w}) problems are shown in Table 2, Total Tardiness and Total Weighted Tardiness (T and T^{w}) problems are shown in Table 3, Number of Tardy jobs and Weighted Number of Tardy jobs (n_T and n_T^{w}) problems are shown in Table 4, Weighted Late Work criterion (Y_w) problems are shown in Table 5, and finally, other cases are shown in Table 6.

Table 1. Literature review for flowshop scheduling with given due date: Single-objective, L_{max}

Case: Single-Objective (L_{max})			
Problem	**Method**	**Algorithm**	**Comment**
$Fm\|prmu,r_j\|L_{max}$ Grabowski et al (1983)	Exact	Branch and Bound	Small problems are solved
$F2\|block, setup\|L_{max}$ Stevens and Gemmill (1997)	Approx.	Two heuristics	Results for small problems are compared with a Dispatching Rule
$Fm\|idm\|L_{max}$ Xiang et al (2000)	Exact	Algorithm	Algorithm based on EDD rule
$Fm\|idm\text{-}ddm\| L_{max}$ Xiang et al (2000)	Exact	Algorithm	Algorithm based on EDD rule
$F2\| setup\|L_{max}$ Allahverdi and Al-Anzi (2002)	Approx.	Four heuristics	Based on Dileepan and Sen (1991)
Fazle Baki and Vickson (2003)	Exact	Dispatching Rule	It outperforms Webster and Baker (1995)
$F2\|nwt,class\text{-}setup\|L_{max}$ Wang and Cheng (2006)	Approx.	Heuristic	Class setup times
$Fm\|nwt,setup\|L_{max}$ Ruiz and Allahverdi (2007)	Approx.	Dominance Rule, Genetic Algorithms	The best results are obtained by the Genetic Algorithm

Table 2. Literature review for flowshop scheduling with given due date: Single-objective, T_{max} and $T^{w}_{\max}$

Case: Single-Objective (T_{max} and T_{max}^{w})			
Problem	**Method**	**Algorithm**	**Comment**
$F2\|\|T_{max}$ Lin (2001)	X	X	The complexity of the problem is analysed
$Fm\|prmu\|T_{max}$ Portougal and Scott (2001)	X	X	Asymptotic convergence is analysed for some Dispatching Rules
Chung et al (2006)	Exact	Branch and Bound	It outperforms Kim (1995) for n ≤ 20
$Fm\|\|T_{max}$ *vs* $Fm\|prmu\|T_{max}$ Liao et al (2006)	Approx.	Tabu Search	Tabu Search is compared to a Genetic Algorithm
$Fm\|prmu\| T^{w}_{max}$ Portougal and Scott (2001)	X	X	Asymptotic convergence is analysed for some Dispatching Rules
$F2\|setup\|T_{max}$ Dileepan and Sen (1991)	Exact	Branch and Bound	Optimality conditions are presented
	Approx.	Heuristics	Heuristics based on EDD

			and Johnson Algorithm
Fm*|*idm*|*T_{max} Xiang et al (2000)	Exact	Algorithm	Algorithm based on EDD rule
***Fm*|*idm-ddm*|T_{max}** Xiang et al (2000)	Exact	Algorithm	Algorithm based on EDD rule
***F2*|*learning-effect*|T_{max}** Wu et al (2007)	Exact	Branch and Bound	Due date ranges are tested
	Approx.	Simulated Annealing	Heuristic compared to the EDD rule

Table 3. Literature review for flowshop scheduling with given due date: Single-objective, T and T^w

Case: Single-Objective (T and T^w)			
Problem	**Method**	**Algorithm**	**Comment**
F2*||*T Lenstra et al (1977)	X	X	The complexity of the problem is analysed
Sen et al (1989)	Exact	Branch and Bound and three heuristics	One heuristic provides optimal solutions in many cases
Kim (1993b)	Approx.	Tabu Search	List scheduling algorithms are adapted from the job-shop case
Kim (1993a)	Exact	Branch and Bound	It outperforms Sen et al (1989)
Pan and Fan (1997)	Exact	Branch and Bound	For small problems is compared to Kim (1993a)
Pan et al (2002)	Exact	Branch and Bound	It outperforms Pan and Fan (1997)
Fm*|*prmu*|*T Kim (1995)	Exact	Branch and Bound	Lower bounds are obtained from some properties
Parthasarathy and Rajendran (1998)	Approx.	Simulated Annealing	The algorithm is evaluated for the weighted case
Hasija and Rajendran (2004)	Approx.	Simulated Annealing	It outperforms Parthasarathy and Rajendran (1998) and Armentano and Ronconi (1999)
Framinan and Leisten (2007)	Approx.	Iterated Greedy and Variable Neighbourhood Search	It outperforms Parthasarathy and Rajendran (1998) and Hasija and Rajendran (2004)
Vallada and Ruiz (2009)	Approx.	Cooperative Metaheuristic	Heuristic compared to Ruiz and Allahverdi (2007), Ruiz and Stützle (2008) and Vallada and Ruiz (2006)
F2*|*prmu*|*T* vs *F2*||*T Raman (1995)	Approx.	Shifting bottleneck procedures	Results for nonpermutation schedules are better
***Fm*|*prmu*|*T* vs *Fm*||*T* and *Fm*|*prmu*|T^w vs *Fm*||T^w** Liao et al (2006)	Approx.	Tabu Search	Heuristic compared to a Genetic Algorithm
F3*||*T Caskey and Storch (1996)	Exact	Dispatching Rules	Comparison among flowshop, job-shop and hybrid shop cases
Fm*||*T Armentano and Ronconi (1999)	Approx.	Tabu Search	It outperforms Kim (1995)

$\boldsymbol{Fm \mid\mid T^w}$ Ow (1985)	Approx.	Idle Time Rule Heuristic	Processing times are proportional to a constant
$\boldsymbol{Fm \mid setup \mid T^w}$ Ruiz and Stützle (2008)	Approx.	Iterated Greedy	It outperforms Parthasarathy and Rajendran (1998), Ruiz and Stützle (2005) and Rajendran and Ziegler (2003)
Parthasarathy and Rajendran (1997)	Approx.	Simulated Annealing	Heuristic compared to Lenstra et al (1977) and Gelders and Sambandam (1978)
$\boldsymbol{Fm, NC_{win} \mid\mid T^w}$ Aggoune et al (2001)	Approx.	Genetic Algorithm	Heuristic compared to randomly generated solutions
$\boldsymbol{Fm \mid prmu, block \mid T}$ Januario et al (2008)	Approx.	Genetic Algorithm	Heuristic compared to Armentano and Ronconi (2000)

Table 4. Literature review for flowshop scheduling with given due date: Single-objective, n_T and n_T^w

Case: Single-Objective (n_T and n_T^w)			
Problem	**Method**	**Algorithm**	**Comment**
$\boldsymbol{F2 \mid\mid n_T}$ Lin (2001)	X	X	The complexity of the problem is analysed
Bulfin and M'Hallah (2003)	Exact	Branch and Bound	It outperforms Hariri and Potts (1989)
$\boldsymbol{Fm \mid prmu \mid n_T}$ Hariri and Potts (1989)	Exact	Branch and Bound	A lower bound based on the single machine problem is used
$\boldsymbol{Fm \mid\mid n_T^w}$ Bulfin and M'Hallah (2003)	Exact	Branch and Bound	
$\boldsymbol{F2 \mid d_j = d \mid n_T^w}$ Jozefowska et al (1994)	Exact	Dispatching Rule	They study similar problems for open and job-shop
Della Croce et al (2000)	Exact	Branch and Bound	Up to 900 jobs
$\boldsymbol{Fm \mid idm\text{-}ddm \mid n_T}$ Xiang et al (2000)	Exact	Algorithm	Algorithm based on EDD rule
$\boldsymbol{F2 \mid class\text{-}setup \mid n_T^w}$ Cheng and Kovalyov (2003)	Approx	Heuristics	Heuristics based on Dispatching Rules
$\boldsymbol{Fm \mid prmu, secondary\text{-}resources \mid n_T}$ Ruiz-Torres and Centeno (2008)	Approx	Simulated Annealing	Limited to small and medium sized problems

Table 5. Summary on literature review for flowshop scheduling with given due date: Single-objective, Y_w

Case: Single-Objective (Y_w)			
Problem	**Method**	**Algorithm**	**Comment**
***F*2||*Y*$_w$** Lin et al (2006)	Exact	Branch and Bound	A lower bound is proposed
$F2\|d_j=d\|Y_w$ Blazewicz et al (2004)	Exact	Dynamic Programming Approach	It is compared to an enumerative method
Blazewicz et al (2004)	Approx.	Heuristic	Heuristic based on Dispatching Rules
Blazewicz et al (2005c)	Exact	Dynamic Programming Approach	It is compared to an enumerative method
Blazewicz et al (2005b)	Approx.	List Scheduling	It is compared to some generated Dispatching Rules
Blazewicz et al (2005b)	Approx.	Simulated Annealing, Tabu Search and Variable Neighbourhood Search	They are compared to Blazewicz et al (2004)
Blazewicz et al (2005a)	Exact	Dynamic Programming Approach	The complexity of the problem is analysed
Blazewicz et al (2008)	Approx.	Simulated Annealing, Tabu Search and Variable Neighbourhood Search	They are compared to Blazewicz et al (2004)

Table 6. Literature review for flowshop scheduling with given due date: Single-objective, Other cases

Case: Single-Objective (Other cases)			
Problem	**Method**	**Algorithm**	**Comment**
Special cases of $F2\|\|n_T$, $F2\|\|T$, $F2\|\|T_{max}$ Koulamas (1998)	Exact	Some methods	The complexity of the problems is analysed
$Fm\|prmu,d_j=d\|\Sigma(C_j-d)$ Gowrishankar et al (2001)	Exact	Branch and Bound	
	Approx.	Heuristic	It is compared to randomly generated solutions
$Fm\|\ p_{ij}=1,d_j=d\|\ max_j(w_j\|C_j-d\|)$ Kaminsky and Lee (2002)	Exact	X	Non-restrictive and restrictive due dates
$F2\|\ prmu\|\Sigma\|C_j-d\|$+***storage cost*** Lauff and Werner (2004)	Approx.	Enumerative method	The complexity of the problems is analysed

3. Flowshop scheduling problems and due date setting

The class of due date assignment problems is a challenging topic and has become quite popular in recent years (Gordon et al., 2002). In this type of problems the due date itself is a decision variable, in contrast to the case analysed in the previous section. Considering the aforementioned reviews in the introduction section about the due date assignment problem, and taking into account the wide literature regarding to the flowshop problem, it is worth mentioning that flowshop problems with due date assignment have received very little attention in the scheduling literature. However, due to its importance, this case is included in this work. To the best of our knowledge, only Birman and Mosheiov (2004), Hall et al (1991), Kaminsky and Lee (2002), Kaminsky and Lee (2008), Mosheiov (2003) present problems with objective related to set due dates in the flowshop layout.

Hall et al (1991) introduce the generalised due date problem and analyse the complexity of some problems in the flowshop case. In particular, the problems are shown NP-complete. Kaminsky and Lee (2008) introduce a novel model for due date quotation in the permutation flowshop environment. The objective is quoted the due date for each job, and jobs must be sequenced on the machines so that all of jobs complete processing on the last machine at or before their due dates. The sum of the quoted due dates is minimised. This objective is defined as the upper bound of the length of the time within which the job has to start processing after it arrives. The release time r_j for each job, and the processing time p_{ij} for each machine and jobs are given, and the decision variables are the due dates d_j and the completion times C_{ij}. According to the off-line and online scheduling algorithms defined by Kaminsky and Hochbaum (2004), Kaminsky and Lee (2002) present off-line asymptotic optimality and preliminary results for the above problem, then, a online algorithm is developed, analysing asymptotic bounds on its performance under some probabilistic assumptions, and finally, the computational results demonstrate the effectiveness of the algorithm. Birman and Mosheiov (2004) present a note on a due date assignment on a two machine flowshop, with the objective to find both the job schedule and the common due date which minimise maximum earliness, tardiness and due-date costs. The authors present a polynomial time solution by a Johnson Algorithm guaranteeing an optimal solution. Mosheiov (2003) studies the problem of minimising the maximal weighted absolute lateness, applying different weights for earliness and tardiness called asymmetric costs. He proposes a linear programming model to determine the due date for a given sequence to solve the problem in an optimal way for the single machine case, and then it is extended for parallel machines and flowshop. Finally Kaminsky and Kaya (2008) tackle the due date quotation problem too, considering a make-to-order supply chain, formed by a manufacturer served by a single supplier and model them as a two machine flowshop in a decentralised model. They consider the centralised model too, where the entire system is operated by a single entity. They propose algorithms for the models, providing a simple and asymptotically optimal online scheduling and due date quotation heuristic for either the manufacturer and the supplier individually in the decentralised system, or both in the centralised. Finally they compare the performance for both systems.

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