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Invited Review

The third comprehensive survey on scheduling problems with setup times/costs

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ABSTRACT

Scheduling involving setup times/costs plays an important role in today's modern manufacturing and service environments for the delivery of reliable products on time. The setup process is not a value added factor, and hence, setup times/costs need to be explicitly considered while scheduling decisions are made in order to increase productivity, eliminate waste, improve resource utilization, and meet deadlines. However, the vast majority of existing scheduling literature, more than 90 percent, ignores this fact. The interest in scheduling problems where setup times/costs are explicitly considered began in the mid-1960s and the interest has been increasing even though not at an anticipated level. The first comprehensive review paper (Allahverdi et al., 1999) on scheduling problems with setup times/costs was in 1999 covering about 200 papers, from mid-1960s to mid-1988, while the second comprehensive review paper (Allahverdi et al., 2008) covered about 300 papers which were published from mid-1998 to mid-2006. This paper is the third comprehensive survey paper which provides an extensive review of about 500 papers that have appeared since the mid-2006 to the end of 2014, including static, dynamic, deterministic, and stochastic environments. This review paper classifies scheduling problems based on shop environments as single machine, parallel machine, flowshop, job shop, or open shop. It further classifies the problems as family and non-family as well as sequence-dependent and sequence-independent setup times/costs. Given that so many papers have been published in a relatively short period of time, different researchers have addressed the same problem independently, by even using the same methodology. Throughout the survey paper, the independently addressed problems are identified, and need for comparing these results is emphasized. Moreover, based on performance measures, shop and setup times/costs environments, the less studied problems have been identified and the need to address these problems is specified. The current survey paper, along with those of Allahverdi et al. (1999, 2008), is an up to date survey of scheduling problems involving static, dynamic, deterministic, and stochastic problems for different shop environments with setup times/costs since the first research on the topic appeared in the mid-1960s.

1. Introduction

Setup time is the time required to prepare the necessary resource (people, machines) to perform a task (operation, job) while setup cost is the cost to set up a resource before the execution of a task, Allahverdi and Soroush (2008). Tens of thousands of papers, addressing different scheduling problems, have appeared in the literature since the first systematic approach to scheduling problems was undertaken in mid-1950s. A survey of the literature on scheduling problems indicates that more than 90 percent of the literature on scheduling problems ignores setup times/costs while Kopanos, Miguel Lainez, and Puigjaner (2009) states that setup times/costs appear in a plethora of industrial and service applications. Ignoring setup times/costs may be valid for some applications; however, it adversely affects the solution quality of some other applications of scheduling. This is because setup process is not a value added factor, and hence, setup times/costs need to be explicitly considered while scheduling decisions are made in order to increase productivity, eliminate waste, and improve resource utilization.

Setup activities are very important in some applications, e.g., printed circuit board assembly, as it was reported that from 20 percent to 50 percent loss of available capacity may arise from setup activities (Liu & Chang, 2000; Trovinger & Bohn, 2005). By reducing setup time, a direct saving of $1.8 million per year was obtained in a printed circuit board assembly plant (Trovinger & Bohn, 2005). Conner (2009) pointed out that 50 percent of the 250 industrial projects, that they have considered contain setup times and when these setup times are applied, 92 percent of the order deadline could be met.

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Loveland, Monkman, and Morrice (2007) addressed the scheduling problem at the manufacturing of Dell Inc. with the objective of minimizing total setup cost and proposed a methodology. As a result, the production volume was increased as much as 35 percent, and thus, Dell Inc. has saved over $1 million per year. Monkman, Morrice, and Bard (2008) proposed another methodology which has reduced the cost up to 21 percent over the savings of Loveland, Monkman, and Morrice (2007).

The interest in scheduling problems where setup times/costs are explicitly considered began in the mid-1960s. Allahverdi and Soroush (2008) presented about 50 different application industries where scheduling with explicit consideration of separate setup times/costs is essential. Some recent applications are provided next.

Pearn, Chung, and Lai (2007) considered integrated circuit assembly scheduling problem while Pearn, Chung, Yang, and Shiao (2008) addressed the wafer probing scheduling problem where both problems involve sequence-dependent setup times. The demand for electronic products has been increasing which has resulted in an increase in producing printed circuit boards (PCBs). Gelogullari and Logendran (2010) and Sabouni and Logendran (2013a, 2013b) pointed out the importance of explicitly considering setup times/costs in the manufacturing of PBS. Ying (2012) addressed the problem of wafer sorting in semiconductor manufacturing, which is usually regarded as the most critical stage in the whole wafer probing process. Ying (2012) and Lin et al. (2011a) pointed out that in wafer sorting scheduling problem, the minimization of total setup times is the primary criterion. Venditti et al. (2010) addressed a practical scheduling problem arising in the packaging department of a pharmaceutical industrial company. They were able to model the problem as a multi-purpose scheduling problem with setup times and proposed an effective algorithm to solve the problem, where computational experiments showed effectiveness of their approach. Motivated by the logistics operations in an express delivery company, Lee and Qi (2009) pointed out that the problem they faced can be considered scheduling problems with sequence-dependent setup times. Santos and Bernardo (2012) describe scheduling at an integrated pulp and paper mill, manufacturing papers for cardboard out of produced pulp, which is a scheduling problem with significant sequence-dependent setups. Motivated by a real-life scheduling problem in a sheet metal processing company in Malaysia, Ying and Bin Mokhtar (2012) formulated the problem as a single machine scheduling problem with sequence-dependent setup times where one of the objectives of the research was minimizing setup times. Chen et al. (2013) addressed a solar cell industry scheduling problem. They indicated that the problem can be modelled as a hybrid flowshop scheduling problem with setup times. Park and Seo (2013) addressed the transporter scheduling problem of ship assembly block operations management, which can be transformed into a parallel machine scheduling problem with sequence-dependent setup times. Bochtis et al. (2013) formulated the problem of finding a schedule for several geographically distributed fields where biomass handling operations have to be carried out involving a number of sequential tasks as a flowshop scheduling problem with sequence-depended setup times. By applying the approach, Bochtis et al. (2013) were able to reduce the total time about 10 percent as compared to a schedule based on the knowledge of the operations manager. Illeez and Guener (2008) addressed the importance of reducing of setup times in scheduling the entrance sequence of various models planned to be manufactured in the same sewing cell. Boctor et al. (2009) addressed the problem of scheduling operations of shoe manufacturing where setup times are considered as significant. Alfieri (2009) indicated that the manufacturing of cardboards involves scheduling problem with sequence-dependent setup times.

The research on scheduling problems with setup times/costs from mid-1960s to mid-1988 was surveyed by Allahverdi et al. (1999) which covered about 200 papers. Allahverdi et al. (2008) surveyed the work on scheduling problems with setup times/costs from mid-1988 to mid-2006 covering about 300 papers. This is the third comprehensive review paper, a continuation of the survey papers by Allahverdi et al. (1999, 2008), which surveys about 500 papers that have appeared from the mid-2006 to the end of 2014. The objective of the current survey paper is to review the literature on scheduling problems with setup times/costs involving static, dynamic, deterministic, and stochastic problems for all shop environments as a single-machine, parallel machines, flowshop (regular flowshop, no-wait flowshop, flexible flowshop, assembly flowshop), job shop, or open shop. Given that so many papers have appeared in a relatively short period of time, different researchers have addressed the same problem independently, by even using the same methodology. Throughout the survey paper, the independently addressed problems are identified, and the need to compare those results is emphasized.

The earlier research that was covered by Allahverdi et al. (2008) is not cited in this survey paper even when a comparison of a new result with a result that was referenced in Allahverdi et al. (2008) is required since otherwise the long list of references would be even longer. Furthermore, some papers even though are covered by Allahverdi et al. (2008) but appeared in the years 2007 and 2008 as the acceptance date of the survey paper by Allahverdi et al. (2008) was June 2006, and hence, are not included since they are already included in Allahverdi et al. (2008) as papers “in press”.

The following scheduling problems are not reviewed; scheduling with lot-sizing, with lot-streaming, with assembly line balancing, with malleable jobs, with vehicle routing, or scheduling with a single server to perform setup operation. Scheduling problems with job families where batch formation is a part of the decision making process are also excluded.

Classification and notation are provided in Section 2, single machine and parallel machine scheduling problems are discussed in Sections 3 and 4, respectively. Flowshop scheduling problems are covered in Section 5 while Section 6 addresses the scheduling problems in job shop and open shop environments. Finally, concluding remarks are made in Section 7.

2. Classification and notation

Scheduling problems can be classified based on a number of factors including the number of stages jobs need to be processed, the number of machines at each stage, job processing requirements, setup time/cost requirements, and the performance measure to be optimized.

Setup times/costs can be classified as sequence-dependent or sequence-independent. Setup times/costs are called sequence-dependent when the time/cost to setup for a given job (product) depends on which job was setup on the resource (machine) prior to running that job.

For example, in manufacturing of clothes, before dyeing a yarn, the dyeing tank (the machine that processes the yarn to be dyed) needs to be cleaned. The setup (cleaning) time necessary to prepare for dyeing a coming job can be different, dependent upon the colors of the coming yarn and the one just finishing dyeing (Hsu et al., 2009). If the preceding job is black and the following one is white, then a full cleaning of the dyeing tank is required. On the other hand, if the preceding job is white color and the following one is black, then just a rough cleaning the dyeing tank is necessary. Therefore, less cleaning time is required when the tank is changed from white to black as opposed to from black to white. Another example is in the printing industry where the cleaning (setup) times of the printing presses depend on the size of paper and the color of ink used by the preceding job.

The two performance measures of “setup time” and “setup cost” can be considered as equivalent if setup time and setup cost are proportional. However, in general, this may not be the case (Allahverdi & Soroush, 2008).

Table 1
Description of α, β, γ fields.

α		β		γ	
Notation	Description	Notation	Description	Notation	Description
1	Single machine	ST_{si}	Sequence-independent setup time	C_{max}	Makespan
P	Parallel machines (identical)	SC_{sd}	Sequence-dependent setup cost	E_{max}	Maximum earliness
Q	Parallel machines (uniform)	ST_{sd}	Sequence-dependent setup time	L_{max}	Maximum lateness
R	Parallel machines (unrelated)	$ST_{si,f}$	Sequence-independent family setup time	T_{max}	Maximum tardiness
Fm	m-stage flowshop	$ST_{sd,f}$	Sequence-dependent family setup time	D_{max}	Maximum delivery time
FFm	m-stage flexible (hybrid) flowshop	$SC_{sd,f}$	Sequence-dependent family setup cost	TSC	Total setup/changeover cost
AFm	m-stage assembly flowshop	ST_{psd}	Past-sequence-dependent setup time	TST	Total setup/changeover time
J	Job shop	$Prec$	Precedence constraints	TNS	Total number of setups
FJ	Flexible job shop	r_j	Non-zero release date	ΣF_j	Total flowtime
O	Open shop			ΣC_j	Total completion time
				ΣE_j	Total earliness
				ΣT_j	Total tardiness
				ΣW_j	Total waiting time
				ΣU_j	Number of tardy (late) jobs
				Σw_jC_j	Total weighted completion time
				Σw_jF_j	Total weighted flowtime
				Σw_jU_j	Weighted number of tardy jobs
				Σw_jE_j	Total weighted earliness
				Σw_jT_j	Total weighted tardiness
				Σw_jW_j	Total weighted waiting time
				$\Sigma h(E_j)$	Total earliness penalties
				$\Sigma h(T_j)$	Total tardiness penalties
				$TADC$	Total absolute differences in completion times

Some scheduling problems consist of a number of job families where each family is a set of jobs that has similar characteristics in terms of setups, tooling and operation sequence. The number of job families is fixed as well as the number of jobs in each family. A setup on a machine is necessary when a job from a different family is to be processed. In other words, there is a negligible setup time/cost to change from one job to another with the same family but a major setup time/cost is needed between job families. The family setup time/cost can be also sequence-dependent or sequence-independent.

Regarding to setup times/costs, the same classification of problems, adopted in the survey paper by Allahverdi et al. (1999, 2008), is used. That is scheduling problems are classified as family and non-family setup times/costs, then for each class, the problem is further divided as sequence-dependent and sequence-independent setup times/costs.

The commonly utilized three-field notation $\alpha/\beta/\gamma$ is used to describe a scheduling problem (Graham et al., 1979). The first field (α) describes the shop (machine) setting. The second field (β) describes the setup information, other shop conditions, and details of the processing characteristics, which may contain multiple entries. For, the setup information though, the description of Allahverdi et al. (2008) is used for clarity purposes. The third field (γ) defines the performance measure. Table 1 describes the three fields in detail. For example, a two-machine flowshop scheduling problem to minimize makespan with family sequence-dependent setup times will be noted as $F2/ST_{sd,f}/C_{max}$.

Minimizing total or mean of a performance measure results in the same solution. Hence, for example, total tardiness (ΣT_j) and mean tardiness ($\Sigma T_j/n$) are equivalent criteria, thus, for simplicity we just refer both by ΣT_j. This has been applied to other performance measures as well.

Papers addressing more than one performance measure can be categorized into two classes. The first class of papers considers the performance measures as separately, which means that they address different problems. For example, if a paper addresses the problem of $1/ST_{sd}/C_{max}, \Sigma T_j$ it means that the paper addresses both of the problems of $1/ST_{sd}/C_{max}$ and $1/ST_{sd}/\Sigma T_j$. The second class takes into account all the performance measures of $Z_1, Z_2, \ldots, Z_k$, i.e., multi-criteria. The notation of T'Kindt and Billaut (2002) is used for the multi-criteria scheduling problems. Therefore, the notation $F_l(Z_1, Z_2, \ldots, Z_k)$ is used when the objective is to minimize a linear combination of the k criteria while the notation of $\#(Z_1, Z_2, \ldots, Z_k)$ is used when a Pareto approach is taken. On the other hand, the notation $Lex(Z_1, Z_2, \ldots, Z_k)$ is utilized when the decision maker is not authorized to make trade-offs between the criteria, and hence, the objective is to minimize Z_1 first, then Z_2, then Z_3 and so on, i.e., by using lexicographical order and optimizing the criteria one after the other. Finally, $\in(Z_1/Z_2, \ldots, Z_k)$ indicates that the objective is to minimize Z_1 subject to the constraints that the other objectives $Z_2, \ldots, Z_k$ have upper bounds while $GP(Z_1, Z_2, \ldots, Z_k)$ denote that the goal programming approach is taken.

Different methods of solution have been proposed in solving scheduling problems. Table 2 describes the abbreviations of the methods that have been used in the papers reviewed in this survey.

The results for single machine, parallel machine, flowshop, job shop and open shop environments are presented in the coming sections, respectively. For each shop environment, the results are summarized in the order of ST_{si}, ST_{sd}, $ST_{si,f}$, and $ST_{sd,f}$. Moreover, the single criterion results are discussed followed by multiple criteria results for each setup time environment. Furthermore, the results for completion time based performance measures are presented followed by due date based performance measures.

Table 2
Description of abbreviations.

ACO	Ant Colony Optimization	IA	Immune Algorithm	PSO	Particle Swarm Optimization
$B\&B$	Branch-and-bound	ICA	Imperialist Competitive Algorithm	$RKGA$	Random Key Genetic Algorithm
DE	Differential Evolution	ILS	Iterated Local Search	SA	Simulated Annealing
EMA	Electro Magnetism-like Algorithm	MA	Memetic Algorithm	TS	Tabu Search
GA	Genetic Algorithm	MIP	Mixed Integer Programming	VNS	Variable Neighborhood Search
$GRASP$	Greedy randomized search procedure	$MILP$	Mixed Integer Linear Programming		

3. Single machine

The literature on scheduling, with setup times/costs, in a single machine environment is presented in this section. Tables 3–5 summarize the work on non-family setup, family setup, and past-sequence-dependent setup, respectively.

3.1. Non-family sequence-dependent setup times (ST_{sd})

Ángel-Bello et al. (2011a) studied the problem of $1/ST_{sd}/C_{max}$ with maintenance. They proposed a *MIP* model, presented a linear relaxation model, and an efficient heuristic procedure to solve larger size problems. Ángel-Bello et al. (2011b) proposed an efficient metaheuristic based on *GRASP*. Pacheco et al. (2013) proposed a heuristic method, hybridization of multi-start strategies with *TS*, for the same problem and they showed that their hybridized heuristic outperform that of Ángel-Bello et al. (2011b). Kaplanoglu (2014) also addressed the problem of $1/ST_{sd}/C_{max}$ with maintenance but for the case of dynamic job arrivals. He proposed a collaborative multi-agent optimization method. On the other hand, Rojas-Santiago et al. (2014) presented a combination of Lagrangian relaxation and a heuristic for the problem of $1/ST_{sd}, r_j/C_{max}$.

Stecco et al. (2008) addressed the problem of $1/ST_{sd}/C_{max}$ where the setup times were not only sequence-dependent but also time-dependent. They proposed a branch-and-cut algorithm and showed that problems up to 50 jobs can be solved. Stecco et al. (2009) presented a *TS* algorithm and showed that the *TS* algorithm finds a better solution in shorter time.

Zammori et al. (2014) proposed a metaheuristic algorithm by integrating *GA* and harmony search for the problem of $1/ST_{sd}/\Sigma T_j, T_{max}, \Sigma(w_{j1}E_j + w_{j2}T_j)$ with maintenance and machine breakdowns.

Ying and Bin Mokhtar (2012) addressed the problem of $1/ST_{sd}/C_{max}$ with the secondary objective of minimizing *TST* where jobs dynamically arrive. They presented a simple heuristic algorithm based dynamic scheduling system for the problem.

Bahalke et al. (2010) developed a mathematical model and presented a *TS* algorithm and a *GA* for the problem of $1/ST_{sd}/C_{max}$ with deteriorating jobs. Job deterioration implies that a job processing time is an increasing function of its execution starting time where any delay in the processing of the job is penalized by incurring additional time.

Bigras et al. (2008) presented B&B algorithms for the problem of $1/ST_{sd}/\Sigma C_j$. They showed that problems up to a size of 50 jobs can be solved in a reasonable time. Chou et al. (2009) presented two exact methods, a constant programming model and a *B&B* algorithm, and two heuristics for the problem of $1/ST_{sd}, r_j/\Sigma w_jC_j$. Nogueira et al. (2015a) proposed and analyzed different *MIP* formulations of the problem of $1/ST_{sd}, r_j/\Sigma w_jC_j$. Their formulations are based on the knowledge of four different paradigms. The best formulation is obtained based on the computational experiments. Kodaganallur et al. (2014) presented a *B&B* algorithm for the problem of $1/ST_{sd}$ with the performance measure of quadratic penalty function of job completion times. They also proposed a greedy stochastic algorithm and integrated the greedy stochastic algorithm in *GA*.

Luo et al. (2006a) and Luo and Chu (2007) presented some dominance relations and proposed *B&B* algorithms for the problem of $1/ST_{sd}/T_{max}$. Chen et al. (2006) presented a *GA* for the problem of $1/ST_{sd}/L_{max}$. The *B&B* algorithms of Luo et al. (2006a) and Luo and Chu (2007) for the problem of $1/ST_{sd}/T_{max}$ have not been compared.

Luo and Chu (2006) and Luo et al. (2006a, 2006b) provided some dominance relations and presented a *B&B* algorithm for the problem of $1/ST_{sd}/\Sigma T_j$. Another *B&B* algorithm was proposed by Bigras et al. (2008) for the same problem. They showed that problems up to a size of 45 jobs can be solved in a reasonable time. The *B&B* algorithms of Luo and Chu (2006) and Luo et al. (2006a) and that of Bigras et al. (2008) have not been compared. An *ACO* heuristic was developed by Wang (2014) and its performance was compared with that of *GA* for the problem of $1/ST_{sd}/\Sigma T_j$ where there is a limited buffer space.

Armentano and De Araujo (2006) presented a memory-based *GRASP* algorithm for the problem of $1/ST_{sd}/\Sigma T_j$ and showed that their procedure outperforms the heuristics from the literature. Arroyo et al. (2009) proposed an *ILS* heuristic for the same problem. They showed that their heuristic is better than *GRASP* and *ACO* algorithms. Akrout et al. (2012) presented a *GRASP* algorithm based on the *DE* and tested the performance of their algorithm based on benchmark instances from the literature. Ouyang and Xu (2014) presented a *GA*, Sioud et al. (2010, 2012a) proposed a hybrid *GA* and Sioud et al. (2012b) presented several heuristics. Sioud et al. (2012b) presented a hybrid approach based on the integration of a *GA* and concepts from constraint programming, multi-objective evolutionary algorithms, and *ACO*. The memory-based *GRASP* heuristic of Armentano and De Araujo (2006), the *ILS* heuristic of Arroyo et al. (2009), the *DE* of Akrout et al. (2012), and hybrid *GA* of Sioud et al. (2012b) have not been compared. Nogueira et al. (2015b) addressed the problem of $1/ST_{sd}, r_j/\Sigma T_j$. They proposed a hybrid Lagrangian metaheuristic, which is a Lagrangian relaxation, integrated with a metaheuristic. They have shown that their proposed approach can solve optimally about 80 percent of the benchmark problems in the literature.

Liao and Juan (2007) presented an *ACO* algorithm, Lin and Ying (2007) proposed *SA*, *GA*, and *TS* algorithms while Valente and Alves (2008) proposed several versions of beam search techniques based algorithms for the problem of $1/ST_{sd}/\Sigma w_jT_j$. Lin and Ying (2008) presented a hybrid *SA* and *TS* algorithm, and showed that their hybrid algorithm performs better than *SA*, *GA*, *TS*, and *ACO*. Cicirello (2009) presented a benchmark instance generator and a set of benchmark instances. Anghinolfi and Paolucci (2009) presented a discrete *PSO* algorithm for the same problem and showed that their discrete *PSO* algorithm outperforms the earlier existing algorithms including the *ACO* of Liao and Juan (2007). Luo et al. (2009b) presented an algorithm, called filter and fan, and showed that the filter and fan algorithm outperforms the *ACO* algorithm of Liao and Juan (2007) and the *SA*, *GA*, *TS* of Lin and Ying (2007). Tasgetiren et al. (2009) proposed a discrete *DE* algorithm by utilizing *GRASP*, referenced local search, and dispatching rules for the same problem. They showed that their algorithm outperform the *PSO* algorithm of Anghinolfi and Paolucci (2009). Bozejko (2010) presented a metaheuristic algorithm based on parallel scatter search and showed that it outperforms the heuristics proposed by Liao and Juan (2007), Lin and Ying (2007), and Valente and Alves (2008). Guo and Tang (2011) presented a scatter based metaheuristic and showed that their heuristic outperforms the *DE* algorithm of Tasgetiren et al. (2009) and the metaheuristic of Bozejko (2010) based on a benchmark problem sets. Luo et al. (2012b) presented an iterated filter-and-fan algorithm for the same problem and showed that their algorithm outperforms *DE* and discrete *PSO*. Deng and Gu (2014) proposed an iterated greedy algorithm and showed that their algorithm performs better than that of Tasgetiren et al. (2009). Kirlik and Oguz (2012) proposed a general *VNS* heuristic and tested their heuristic on the benchmark instances from the literature. On the other hand, Subramanian et al. (2014) developed an *ILS* heuristic for the problem and compared its performance with the discrete *PSO* of Anghinolfi and Paolucci (2009), discrete *DE* of Tasgetiren et al. (2009), and general *VNS* of Kirlik and Oguz (2012). Xu et al. (2014b) presented an *ILS* algorithm while Xu et al. (2014c) proposed hybrid evolutionary algorithms for the problem. The heuristics of Guo and Tang (2011), Luo et al. (2012b), Deng and Gu (2014), Subramanian et al. (2014), and Xu et al. (2014c) have not been compared.

Tanaka and Araki (2013) proposed an exact algorithm for the problem of $1/ST_{sd}/\Sigma w_jT_j$. Their algorithm is based on successive sublimation dynamic programming. They showed that their algorithm can optimally solve almost all benchmark instances in the literature. Neammanee and Reodecha (2009) considered the problem of $1/ST_{sd}/\Sigma w_jT_j$ where the machine has a constrained feeder capacity.

Table 3
Single machine non-family setup time scheduling problems (ST_{sd}).

Setup type	References	Criterion (comments)	Approach
ST_{sd}	Akrout et al. (2012)	ΣTj	*GRASP* based on *DE*
	Ang et al. (2009)	*Cycle time*, ΣT_j (*dynamic job arrivals*)	Different dispatching rules
	Ángel-Bello et al. (2011a)	C_{max} (*maintenance*)	*MIP* model, relaxation, heuristic procedure
	Ángel-Bello et al. (2011b)	C_{max} (*maintenance*)	Metaheuristic using *GRASP*
	Anghinolfi and Paolucci (2009)	Σw_jT_j	Discrete *PSO*
	Armentano and De Araujo (2006)	ΣT_j	Memory-based *GRASP*
	Arroyo et al. (2009)	ΣT_j	ILS heuristic which uses *GRASP* to generate an initial solution
	Atighehchian and Sepehri (2013)	Σw_jT_j (*dynamic job arrivals*)	Combination of *SA* and neural network
	Bahalke et al. (2010)	C_{max} (*deteriorating jobs*)	Math model, *TS*, *GA*
	Bigras et al. (2008)	ΣC_j	*B&B* algorithm
	Bigras et al. (2008)	ΣT_j	*B&B* algorithm
	Bozejko (2010)	Σw_jT_j	Parallel scatter search metaheuristic
	Chang et al. (2011)	$\Sigma(E_j+T_j)$	Dominance relations, *GA*, *GA* combined with dominance relations
	Chen (2008b)	*TST* (*maintenance*)	Heuristic
	Chen (2009b)	*TST* (*maintenance*)	Heuristic
	Chen and Chen (2011)	$\Sigma(E_j+T_j)$ (*common due date*)	Extended artificial chromosomes with *GA*
	Chen et al. (2006)	L_{max}	*GA*
	Chen et al. (2007)	$\Sigma(E_j+T_j)$	Dominance relations, GA including dominance relations
	Chen et al. (2014)	$\Sigma(E_j+T_j)$ (*common due date*)	Artificial chromosomes with *GA*
	Choobineh et al. (2006)	$GP(C_{max}, \Sigma T_j, \Sigma U_j)$	*MILP*, *TS*
	Chou et al. (2009)	Σw_jC_j (r_j)	*B&B* algorithm, a constraint programming model, heuristics
	Cicirello (2009)	Σw_jT_j	Benchmark instance generator
	Deng and Gu (2014)	Σw_jT_j	An iterated greedy algorithm
	Guo and Tang (2011)	Σw_jT_j	Scatter search based metaheuristic
	Hepdogan et al. (2009)	$\Sigma(E_j+T_j)$	Metaheuristic based on randomized priority search
	Iranpoor et al. (2012)	F_l (ΣE_j, ΣT_j, Σd)	*B&B* algorithm, metaheuristics based on *ACO* and *GRASP*
	Jula and Kones (2013)	*To sustain a desired level of WIP with* C_{max}, *as a secondary objective*	Two-step goal *MIP*, insertion heuristics
	Jula and Rafiey (2012)	*To sustain a desired level of WIP*	Network-based algorithms
	Kaplanoglu (2014)	C_{max} (*dynamic job arrivals, maintenance*)	*Multi-agent based optimization method*
	Kodaganallur et al. (2014)	*Quadratic penalty function of completion times*	*B&B* algorithm, greedy stochastic algorithm, *GA*
	Kim and Lee (2009)	*Sum of penalties associated with earliness, tardiness, and due date*	Dominance relations, lower and upper bounds, *B&B* algorithm
	Kirik and Oguz (2012)	Σw_jT_j	A general VNS heuristic
	Lee et al. (2012b)	*TST*	Constructive heuristic
	Li and Qiao (2008)	Σw_jT_j (*dynamic job arrivals*)	*ACO*
	Liao et al. (2012)	Σw_jT_j	Time complexities
	Liao and Juan (2007)	Σw_jT_j	*AOC* algorithm
	Lin and Ying (2007)	Σw_jT_j	*SA*, *GA*, *TS*
	Lin and Ying (2008)	Σw_jT_j	Hybrid of *SA* and *TS*
	Luo and Chu (2006)	ΣT_j	Dominance relations, lower bounds, *B&B* algorithm
	Luo and Chu (2007)	T_{max}	Dominance relations, *B&B* algorithm
	Luo et al. (2006a)	T_{max}, ΣT_j	Dominance relations, *B&B* algorithm
	Luo et al. (2006b)	ΣT_j	Dominance relations, *B&B* algorithm
	Luo et al. (2009b)	Σw_jT_j	Filter-and-fan algorithm
	Luo et al. (2012b)	Σw_jT_j	Iterated filter-and-fan algorithm
	Neammanee and Reodecha (2009)	Σw_jT_j(*constrained feeder capacity*)	*MA* including *GA*, local search, and dispatching rules
	Nekoiemehr and Moslehi (2011)	F_l (E_{max}, T_{max})	Dominance relations, *B&B* algorithm
	Nogueira et al. (2015b)	ΣT_j (r_j)	*A hybrid Lagrangian metaheuristic*
	Nogueira et al. (2015a)	Σw_jC_j	*MIP* formulations
	Nogueira et al. (2015a)	Σw_jT_j	*MIP* formulations
	Ozcelik and Sarac (2010)	F_l (C_{max}, ΣT_j)	*GA*
	Ozgur and Bai (2010)	*TST*	Hierarchical composition procedure
	Pacheco et al. (2013)	C_{max}	A hybridized heuristic of multi-start strategies with *TS*
	Quyang and Xu (2014)	ΣT_j	*GA*
	Rabadi et al. (2007)	$\Sigma(E_j+T_j)$	*SA*, hybrid *SA*
	Rajas-Santiago et al. (2014)	C_{max} (r_j)	Lagrangian Relaxation, heuristic
	Ribeiro et al. (2009)	$\Sigma(w_{j1}E_j+w_{j2}T_j)$	Adaptive *GA*
	Ribeiro et al. (2010)	$\Sigma(w_{j1}E_j+w_{j2}T_j)$	Adaptive *GA*
	Subramanian et al. (2014)	Σw_jT_j	An ILS heuristic
	Sioud et al. (2010)	ΣT_j	Hybrid *GA*
	Sioud et al. (2012a)	ΣT_j	Hybrid *GA*
	Sioud et al. (2012b)	ΣT_j	Hybrid *GA*
	Stecco et al. (2008)	C_{max} (*setup times also time-dependent*)	Branch-and-cut algorithm
	Stecco et al. (2009)	C_{max} (*setup times also time-dependent*)	*TS*
	Tanaka and Araki (2013)	Σw_jT_j	An exact algorithm based on successive sublimation dynamic programming
	Tasgetiren et al. (2009)	Σw_jT_j	Discrete *DE* algorithm
	Valente and Alves (2008)	Σw_jT_j	Different versions of beam search technique based algorithms
	Wang (2013)	#(ΣC_j, *maximum expected time of failure*) (*maintenance*)	Two versions of *GA*
	Wang (2014)	ΣT_j (*limited buffer space*)	ACO
	Xu et al. (2014b)	Σw_jT_j	ILS
	Xu et al. (2014c)	Σw_jT_j	Hybrid evolutionary algorithms
	Ying and Bin Mokhtar (2012)	C_{max} *with secondary objective of TST* (*dynamic job arrivals*)	Simple heuristic algorithm based on dynamic scheduling system
	Ye at al. (2006)	*TST*	New version of *ACO*
	Zammori et al. (2014)	ΣT_j, T_{max}, $\Sigma(w_{j1}E_j+w_{j2}T_j)$ (*maintenance, machine breakdowns*)	Metaheuristic integrating *GA* and harmony search

Table 4
Single machine family setup time scheduling problems ($ST_{si,f}$, $ST_{sd,f}$).

Setup type	References	Criterion (comments)	Approach
$ST_{si,f}$	Bai et al. (2012b)	C_{max}, ΣC_j (*learning effect, deterioration*)	Polynomial solutions
	Cheng et al. (2011a)	T_{max} (*deterioration*)	*B&B* algorithm
	Gupta and Chantaravarapan (2008)	ΣT_j	*MILP*, tow-phase heuristics including *SA*
	Hazir et al. (2008)	ΣF_j	*SA, GA, TS, ACO*
	He and Sun (2012)	ΣC_j (*deterioration*)	Polynomial solution under certain case
	Huang et al. (2011)	C_{max}, *total resource consumption* (*learning effect, deterioration*)	Polynomial solutions
	Lee and Lu (2012)	$\Sigma w_j U_j$ (*deterioration*)	Dominance relations, *B&B* algorithm
	Lee and Wu (2010)	C_{max} (*deterioration*)	Polynomial solution
	Lee et al. (2011)	ΣU_j (*deterioration*)	Dominance relations, lower bound, *B&B* algorithm
	Li et al. (2011b)	*A cost function including earliness, tardiness, flow time penalties*	Polynomial time algorithm
	Liu et al. (2009)	L_{max}	Heuristic
	Omar et al. (2008)	$\Sigma w_j T_j$	*TS*
	Wang et al. (2008)	C_{max}, $\Sigma w_j C_j$ (*deterioration*)	Polynomial solution
	Wang et al. (2012)	C_{max} (*deterioration*, r_j)	Polynomial solution under certain conditions
	Wei and Wang (2010)	$\sum w_j C_j^2, \sum w_j W_j^2$ (*deterioration*)	Polynomial time algorithms
	Wu and Lee (2008)	C_{max} (*deterioration*)	Polynomial solution
	Wu and Lee (2008)	ΣC_j (*deterioration*)	Polynomial solution under certain condition, heuristic
	Xu et al. (2014a)	C_{max} (*deterioration, rj*)	Polynomial solution under certain conditions, heuristic
	Yang (2011)	C_{max} (*learning effect, deterioration*)	Polynomial solution
	Yang (2011)	ΣC_j (*learning effect, deterioration*)	Polynomial solution under certain conditions
	Yang and Chand (2008)	C_{max} (*learning and forgetting effects*)	*B&B* algorithm
	Yang and Yang (2010)	C_{max} (*learning effect, deterioration*)	Polynomial solution
	Yang and Yang (2010)	ΣC_j (*learning effect, deterioration*)	Polynomial solution under certain conditions
$ST_{sd,f}$	Chen (2008a)	*Tmax* (*setup times affected due to vacations*)	Dominance relation, *B&B* algorithm, heuristic
	Ivanov et al. (2009)	C_{max}	Algorithm
	Jin et al. (2009a)	L_{max}	Dominance relations, *TS*
	Jin et al. (2009b)	L_{max}	Dominance relations, *SA*
	Jin et al. (2010)	L_{max}	Dominance relations, *TS*
	Lu et al. (2012)	*Absolute deviation of total flow time* (*uncertain processing and setup times*)	*SA* based heuristic, formulation
	Rego et al. (2012)	$\#(T_{max}, \Sigma T_j)$	Multi-objective heuristics based on *VNS*, Pareto *ILS*

They proposed an *MA* which includes *GA*, local search, and some dispatching rules. Atighehchian and Sepehri (2013) addressed the problem of $1/ST_{sd}/\Sigma w_j T_j$ for the case of dynamic job arrivals. They proposed a combination of *SA* and a multi-layer feed-forward neural network heuristic and showed that it performs well.

Liao et al. (2012) addressed the problem of $1/ST_{sd}/\Sigma w_j T_j$. They improved the complexities of searching the interchange, insertion, and twist neighborhoods from $O(n^3)$ to $O(n^2 \log n)$. Li and Qiao (2008) presented an *ACO* algorithm for the problem of $1/ST_{sd}/\Sigma w_j T_j$ for the case of dynamic job arrivals. They showed that the *ACO* performs 40 percent better than the current practice of the problem. Nogueira et al. (2015a) proposed different *MIP* formulations for the problem of $1/ST_{sd}, r_j/\Sigma w_j T_j$. The best formulation is obtained based on the computational experiments.

Ye et al. (2006) presented a new version of *ACO* algorithm called Branching Ant Colony with Dynamic Perturbation for the problem of $1/ST_{sd}/TST$. They showed that the new version of *ACO* performs better than the regular *ACO*. Ozgur and Bai (2010) considered the same problem and presented a hierarchical composition procedure with negligible computation time. The hierarchical method of Ozgur and Bai (2010) and the *ACO* of Ye et al. (2006) need to be compared.

Lee et al. (2012b) addressed the problem of $1/ST_{sd}/TST$ with multi-attribute setup times originated from the manufacturing plant of a company producing *PVC* sheets. In this problem, each job has several attributes and each attribute has one or more levels. Because there is at least one different level of attribute between two adjacent jobs, it is necessary to make a setup adjustment whenever there is a switch to a different job. The authors proposed a constructive heuristic, which is based on several theorems that they developed. Chen (2008b, 2009b) considered the problem of $1/ST_{sd}/TST$ with maintenance. They proposed a heuristic and evaluated its performance by using a *B&B* algorithm. Lee, Liao, and Chung (2014) addressed the same problem of Lee et al. (2012b) with multi-attribute setup times to minimize C_{max} for the two identical parallel machine environments.

Rabadi et al. (2007) proposed an *SA*, a heuristic, and a hybrid of the heuristic and *SA* for the problem of $1/ST_{sd}/\Sigma(E_j + T_j)$. They showed that the hybrid heuristic outperforms the other two heuristics. Chen et al. (2007) presented some dominance relations and proposed a *GA* which utilized the dominance relations. Hepdogan et al. (2009) presented a metaheuristic while Chang et al. (2011) presented some dominance relations for the same problem. Chang et al. (2011) combined these dominance relations with *GA* and showed that the combined metaheuristic performs much better than the single *GA*. Chen and Chen (2011) and Chen et al. (2014) presented an extended artificial chromosomes with *GA* for the same problem and showed that their algorithm outperforms those of Rabadi et al. (2007) and Chang et al. (2011). The GA of Chen et al. (2007), the metaheuristic of Hepdogan et al. (2009), and the GA of Chen and Chen (2011) have not been compared.

Ribeiro et al. (2009, 2010) presented an adaptive *GA* for the problem of $1/ST_{sd}/\Sigma(w_{j1}E_j + w_{j2}T_j)$. Nekoiemehr and Moslehi (2011) provided some dominance relations and presented a *B&B* algorithm for the problem of $1/ST_{sd}/F_l(E_{max}, T_{max})$.

Ozcelik and Sarac (2010) presented a *GA* for the problem of $1/ST_{sd}/F_l(C_{max}, \Sigma T_j)$. They evaluated its performance based on randomly generated data showing that it performs well.

Kim and Lee (2009) addressed the problem of $1/ST_{sd}$ with the objective of minimizing the sum of penalties associated with earliness, tardiness, and due date assignment (common due date). They provided some dominance relations and presented lower and upper bounds. They also proposed a *B&B* algorithm by utilizing the dominance relations, lower and upper bounds.

Table 5
Single machine past-sequence-dependent setup time scheduling problems (ST_{psd}).

References	Criterion (comments)	Approach
Bai et al. (2012a)	C_{max}, ΣC_j, $\sum C_j^2$(*general exponential learning effect*)	Polynomial solutions
Bai et al. (2012a)	L_{max}, $\Sigma w_j C_j$ (*general exponential learning effect*)	Polynomial solutions under certain conditions
Cheng et al. (2010)	C_{max}, ΣC_j, $\sum C_j^2$ (*deteriorating jobs, learning effect, proportional setup times*)	Polynomial solutions
Cheng et al. (2010)	L_{max}, ΣT_j (*deteriorating jobs, learning effect, proportional setup times*)	Polynomial solutions when processing times and due dates are agreeable
Cheng et al. (2011b)	C_{max}, ΣC_j, $\sum C_j^2$ (*deteriorating jobs*)	Polynomial solutions
Cheng et al. (2011b)	L_{max}, ΣT_j (*deteriorating jobs*)	Polynomial solutions when processing times and due dates are agreeable
Huang (2012)	ΣUj (*effects of learning and deterioration*)	Counter example of one of the results of Yin et al. (2010b)
Huang et al. (2013)	C_{max}, ΣC_j, $\sum C_j^r$ ($r>0$) (*deteriorating jobs, learning effect*)	Polynomial solutions
Huang et al. (2013)	L_{max}, $\Sigma w_j C_j$	Polynomial solutions under certain conditions
Kuo and Yang (2007)	C_{max}, ΣC_j, *TADC* (*learning effect*)	Polynomial solutions
Lai et al. (2011)	C_{max}, ΣC_j (*deteriorating jobs*)	Polynomial solutions
Lai et al. (2011)	L_{max}, T_{max}, $\Sigma w_j C_j$, ΣT_j (*deteriorating jobs*)	Polynomial solutions under certain conditions
Lee (2011)	C_{max}, ΣC_j (*learning effect*)	Polynomial solutions
Lee (2011)	L_{max}, T_{max}, $\Sigma w_j C_j$, ΣT_j (*learning effect*)	Polynomial solutions under certain conditions
Low and Lin (2012)	C_{max}, ΣC_j (*leaning effect, job families*)	Polynomial solutions
Mani et al. (2010)	*TADC*	Polynomial solutions
Mani et al. (2011)	*TADC* (*learning effect*)	Polynomial solutions
Shen et al. (2012)	$\Sigma w_j C_j$ (*effects of learning and deterioration*)	Counter example of one of the results of Yin et al. (2010b)
Soroush (2012a)	*A linear combinations of* C_{max}, ΣC_j, *and absolute difference in completion times*	*B&B* algorithm
Soroush (2012a)	*A linear combinations of* C_{max}, ΣC_j, *and absolute difference in completion times*	Polynomial solutions under certain conditions
Soroush (2012b)	C_{max}, ΣL_j, ΣC_j, ΣW_j, *TADC* (*job dependent, learning effect*)	*B&B* algorithm
Soroush (2012b)	C_{max}, ΣL_j, ΣC_j, ΣW_j, *TADC* (*job dependent, learning effect*)	Polynomial solutions under certain conditions
Soroush (2013)	$\Sigma h(E_j)$ *subject to no tardy jobs* (*learning effect*)	Polynomial solutions
Toksari et al. (2010)	C_{max}, $\sum C_j^2$ (*effects of learning and deterioration*)	Polynomial solutions
Wang (2008)	C_{max}, ΣC_j, *sum of quadratic job completion times* (*time-dependent learning effect*)	Polynomial solutions
Wang et al. (2009b)	C_{max}, ΣC_j, $\sum C_j^r$ ($r>0$) (*effects of learning and deterioration*)	Polynomial solutions
Wang et al. (2009b)	L_{max}, $\Sigma w_j C_j$, ΣU_j (*effects of learning and deterioration*)	Polynomial solutions under certain conditions
Wang et al. (2009c)	C_{max}, ΣC_j, *sum of quadratic job completion times* (*exponential time-dependent learning effect*)	Polynomial solutions
Wang et al. (2009c)	L_{max}, $\Sigma w_j C_j$ (*exponential time-dependent learning effect*)	Polynomial solutions under certain conditions
Wang et al. (2010b)	ΣW_j, *sum of quadratic job completion times, and* $\Sigma h(E_j)$ *subject to no tardy jobs* (*learning effect*)	Polynomial solutions
Wang et al. (2010b)	L_{max}, $\Sigma w_j C_j$ (*learning effect*)	Polynomial solutions under certain conditions
Wang and Li (2011)	C_{max}, ΣC_j, ΣL_j, $\sum C_j^r$ ($r>0$) (*effects of learning and deterioration*)	Polynomial solutions
Wang and Li (2011)	L_{max}, T_{max}, $\Sigma w_j C_j$, ΣU_j (*effects of learning and deterioration*)	Polynomial solutions under certain conditions
Xu et al. (2011)	*Those of* Yin et al. (2010b)	Provided an additional condition for jobs to remain deteriorating
Wang and Wang (2013)	C_{max}, ΣL_j, $\sum C_j^r$ ($r>0$) (*general effect of learning and deterioration*)	Polynomial solutions
Wang and Wang (2013)	L_{max}, T_{max}, ΣT_j, $\Sigma w_j C_j$ (*general effect of learning and deterioration*)	Polynomial solutions under certain conditions
Xu and Zhao (2008)	C_{max} (r_j)	Polynomial solution
Yin et al. (2010a)	C_{max}, $\sum C_j^r$ ($r>0$) (*general learning effect*)	Polynomial solutions
Yin et al. (2010a)	L_{max}, $\Sigma w_j C_j$ (*general learning effect*)	Polynomial solutions under certain conditions
Yin et al. (2010b)	C_{max}, ΣC_j, $\sum C_j^r$ ($r>0$) (*effects of learning and deterioration*)	Polynomial solutions
Yin et al. (2010b)	L_{max}, $\Sigma w_j C_j$, ΣU_j (*effects of learning and deterioration*)	Polynomial solutions under certain conditions
Yin et al. (2011a)	ΣU_j (*effects of learning and deterioration*)	Counter example of one of the results of Wang et al. (2009b)
Yin et al. (2011b)	ΣU_j (*effects of learning and deterioration*)	Counter example of one of the results of Wang and Li (2011)
Yin et al. (2012)	C_{max}, ΣL_j, $\sum C_j^r$ ($r>0$), $\Sigma h(E_j)$ (*effects of learning and deterioration simultaneously*)	Polynomial solutions
Yin et al. (2012)	L_{max}, T_{max}, ΣT_j, $\Sigma w_j h(E_j)$, $\Sigma w_j C_j$ (*effects of learning and deterioration simultaneously*)	Polynomial solutions under certain conditions
Yin et al. (2013)	C_{max} (*family setup time, learning effect*)	Polynomial solutions
Yin et al. (2013)	ΣC_j, $\Sigma w_j C_j$ (*family setup time, learning effect*)	Polynomial solutions under certain conditions
Zhao and Tang (2010)	C_{max}, ΣC_j, *other performance measures* (*deteriorating jobs*)	Polynomial solutions

Ang et al. (2009) considered the problem of $1/ST_{sd}$ with conflicting objective functions such as average cycle time, average tardiness, and their standard deviations for the dynamic job arrival case. They proposed eight different dispatching rules and evaluated their performance by simulations.

Iranpoor, Ghomi, and Zandieh (2012) presented a time dependent traveling salesman problem formulation for the problem of $1/ST_{sd}/F_l(\Sigma E_j, \Sigma T_j, \Sigma d)$ under a maintenance type, rate modifying activity, where d denotes the common due date of the jobs. They also presented a *B&B* algorithm which can solve problems up to 30 jobs in a reasonable amount of time. They also presented two metaheuristics based on *ACO* and *GRASP* and showed that the one based on *ACO* performs better.

Jula and Rafiey (2012) proposed network-based algorithms for the problem of $1/ST_{sd}$ with strictly enforced time window constraints at the start time of each job to sustain a desired level of work in process. They compared the effectiveness, efficiency, and robustness of their proposed algorithms with an exhaustive search approach. Jula and Kones (2013) addressed the same problem with a secondary objective of minimizing makespan. They proposed a two-step goal *MIP* model and presented insertion based heuristics.

Wang (2013) presented two versions of the *GA* for the problem of $1/ST_{sd}/\#(\Sigma C_j$, *maximum expected time of failure*) with preventive machine maintenance. Choobineh et al. (2006) addressed the problem of $1/ST_{sd}/GP(C_{max}, \Sigma T_j, \Sigma U_j)$. They presented a *MILP* formulation for the problem and proposed a multi-objective TS heuristic.

3.2. Family sequence-independent setup times ($ST_{si,f}$)

Wu and Lee (2008) and Lee and Wu (2010) considered the problem of $1/ST_{si,f}/C_{max}$ with deteriorating setup and processing times. They developed polynomial solutions for the problem. Yang and Chand (2008) addressed the problem of $1/ST_{si,f}/C_{max}$ with learning and forgetting effects. They presented some dominance relations and proposed a *B&B* algorithm. Bai et al. (2012b) addressed the problem of $1/ST_{si,f}/C_{max}$ with general deterioration and learning effect. They showed that the problem is polynomially solvable. Yang and Yang (2010) and Yang (2011) addressed the problem of $1/ST_{si,f}/C_{max}$ with simultaneous considerations of learning and deteriorating effects for different functions. They showed that the problem remains polynomially solvable. Wang et al. (2008) showed that the problem of $1/ST_{si,f}/C_{max}$ remain polynomially solvable for the case of deteriorating jobs where both family setup times and processing times are proportional to a linear function of time.

Wang et al. (2012) considered the problem of $1/ST_{si,f}, r_j/C_{max}$ with deteriorating jobs. They showed that under certain conditions, the problem is polynomially solvable. Xu et al. (2014a) addressed the same problem and showed that the problem can be solved under certain conditions polynomially while they proposed a heuristic algorithm for the general case. They showed that the error of their heuristic is very small.

The problem $1/ST_{si,f}/\Sigma C_j$ with deteriorating setup and processing times was addressed by Wu and Lee (2008) and He and Sun (2012). Wu and Lee (2008) showed that the problem is polynomially solvable under certain condition and presented a heuristic for the general problem. He and Sun (2012) showed that the problem is polynomially solvable under the agreeable condition. Bai et al. (2012b) addressed the problem of $1/ST_{si,f}/\Sigma C_j$ with general deterioration and learning effect. They showed that the problem is polynomially solvable. Yang and Yang (2010) and Yang (2011) addressed the problem of $1/ST_{si,f}/\Sigma C_j$ with simultaneous considerations of learning and deteriorating effects. They showed that the problem is polynomially solvable under certain conditions. Wang et al. (2008) showed the problem of $1/ST_{si,f}/\Sigma w_j C_j$ remain polynomially solvable for the case of deteriorating jobs where both family setup times and processing times are proportional to a linear function of time.

Liu, Wang, and Jin (2009) proposed a heuristic algorithm for the problem of $1/ST_{si,f}/L_{max}$. Hazir et al. (2008) presented four heuristics, *SA*, *GA*, *TS*, and *ACO* for the problem of $1/ST_{si,f}/\Sigma F_j$. They showed that *TS* and *ACO* perform better than *SA* and *GA*. Cheng et al. (2011a) presented a *B&B* algorithm for the problem $1/ST_{si,f}/T_{max}$ with deteriorating jobs where a job processed later consumes more time than the same job when it is processed earlier.

Gupta and Chantaravarapan (2008) presented an *MILP* model for the problem $1/ST_{si,f}/\Sigma T_j$. They also proposed two-phase heuristic algorithms, including *SA*. Empirical results indicated that the heuristics are effective. Omar et al. (2008) presented a two-level heuristic algorithm for the problem of $1/ST_{si,f}/\Sigma w_j T_j$. They first developed an apparent tardiness cost with setups at the first level, and then they proposed a *TS* algorithm at the second level.

Lee et al. (2011) developed several dominance relations and a lower bound for the problem of $1/ST_{si,f}/\Sigma U_j$ with deteriorating setup and processing times. They also proposed a heuristic to find an upper bound for their developed *B&B* algorithm. Lee and Lu (2012) provided some dominance relations for the problem of $1/ST_{si,f}/\Sigma w_j U_j$ with deteriorating jobs.

Wei and Wang (2010) presented polynomial time algorithms for the problems $1/ST_{si,f}/\sum w_j C_j^2$ and $1/ST_{si,f}/\sum w_j W_j^2$ for the case of simple linear deteriorating jobs.

Li et al. (2011b) provided a polynomial time algorithm for the problem of $1/ST_{si,f}$ with the objective of minimizing a cost function that includes earliness, tardiness, due date assignment, and flow time penalties.

Huang et al. (2011) addressed the problem of $1/ST_{si,f}$ with simultaneous considerations of learning and deteriorating effects with two different objective functions; minimizing C_{max} subject to the constraint that total resource consumption does not exceed a certain value, and minimizing total resource consumption subject the constraint that C_{max} does not exceed a certain value. They showed that both problems are polynomially solvable.

3.3. Family sequence-dependent setup times ($ST_{sd,f}$)

Ivanov et al. (2009) proposed an efficient algorithm for the problem of $1/ST_{sd,f}/C_{max}$ such that the machine has additional assumptions which was motivated by *MRI* systems. The problem of $1/ST_{sd,f}/T_{max}$ was addressed by Chen (2008a) where setup times are affected, by 2 hours, if the setup time is interrupted due to worker vacations. They proposed a dominance relation, a *B&B* algorithm, and a heuristic to solve the problem.

Jin et al. (2009a, 2010) developed dominance relations and presented a *TS* algorithm for the problem of $1/ST_{sd,f}/L_{max}$. They showed that the *TS* algorithm performs well when compared with the current solution of the industrial problem that they considered. Jin et al. (2009b) presented an *SA* algorithm for the same problem. The *TS* algorithm of Jin et al. (2009a, 2010) and the *SA* algorithm of Jin et al. (2009b) have not been compared.

Lu et al. (2012) addressed the problem of $1/ST_{sd,f}$ with the objective of minimizing absolute deviation of total flow time from the optimal solution under the worst case scenario. They considered both processing and setup times are uncertain within certain intervals. They formulated the problem as a robust constrained shortest path problem and proposed an *SA* based heuristic algorithm to solve the problem.

Rego et al. (2012) addressed the problem of $1/ST_{sd,f}/\#(C_{max}, \Sigma T_j)$, and proposed two multi-objective heuristics and a multi-objective heuristic based on Pareto *ILS*. They showed that the heuristic based on Pareto *ILS* performs better than the others.

3.4. Past-sequence-dependent setup times (ST_{psd})

Koulamas and Kyparisis (2008) introduced the concept of past-sequence-dependent setup times where the setup time is defined to be dependent on the jobs that have already been scheduled. In other words, the setup time of a job is proportionate to the sum of processing times of the jobs already scheduled.

Some papers addressed the problem for learning and/or deterioration effects for the past sequence-dependent setup times. Different learning and/or deterioration functions have been used by different papers. Explanation of the exact functions for learning and/or deterioration effects used for each paper would make the currently long paper even longer, and hence, the explanation of specific functions has not been given.

Biskup and Herrmann (2008) addressed the problem of $1/ST_{psd}$ in the presence of due dates. They considered different due date related performance measures. They showed that some problems remain polynomially solvable even when the setup times are dependent on the sequence of the already scheduled jobs while some other problems do not necessarily remain polynomially solvable. Xu and Zhao (2008) presented a polynomial solution algorithm for the problem of $1/ST_{psd}, r_j/C_{max}$. Mani et al. (2010) presented a polynomial algorithm for the problem of $1/ST_{psd}$ with the performance measure of *TADC*.

Kuo and Yang (2007) addressed the problem of $1/ST_{psd}$ with learning effect. They showed that the problems, with the performance measures of C_{max}, ΣC_j, *TADC*, sum of earliness, tardiness, and common due date penalties, can be solved in polynomial times. Mani et al. (2011) addressed the problem with the *TADC* performance measure. Lee (2011) considered the problem with a general learning effect and showed that the problem with respect to minimizing C_{max} and ΣC_j

are polynomially solvable. He also showed that the problems with respect to the performance measures of L_{max}, T_{max}, ΣT_j and $\Sigma w_j C_j$ are solvable under certain conditions. Wang et al. (2010b) showed the problem with the performance measures of ΣW_j, total absolute difference in waiting time, sum of quadratic job completion times, and $\Sigma h(E_j)$ subject to no tardy jobs are polynomially solvable while those with the performance measures of L_{max} and $\Sigma w_j C_j$ are polynomially solvable under certain conditions. Soroush (2013) showed that the result of Wang et al. (2010b) for the performance measure of $\Sigma h(E_j)$ subject to no tardy jobs is incorrect, and hence he proposed polynomial time solution for the problem. Wang (2008) extended the results of Kuo and Yang (2007) with a time-dependent learning effect. The performance measures Wang (2008) considered were C_{max}, ΣC_j, and the sum of quadratic job completion times. Bai et al. (2012a) addressed the problem of $1/ST_{psd}$ with general exponential learning effect. They showed that the problems, with the performance measures of C_{max}, ΣC_j, $\sum C_j^2$, can be solved in polynomial times while the problem with performance measures of L_{max} and $\Sigma w_j C_j$ are solvable under certain conditions.

Wang et al. (2009c) addressed the problem of $1/ST_{psd}$ with exponential time-dependent learning effect and showed that the problem with the performance measures of C_{max}, ΣC_j, and the sum of quadratic job completion times are polynomially solvable while the problem remains polynomially solvable under certain cases with respect to $\Sigma w_j C_j$ and L_{max}.

Zhao and Tang (2010) addressed the problem of $1/ST_{psd}$ with respect to the performance measures of C_{max}, ΣC_j, and weighted sum *of* earliness, tardiness, due-window starting time and size penalties with deteriorating jobs and with the assumption that job processing time are defined by functions, which are dependent on their starting times. They proposed polynomial time algorithms to solve the problems.

Cheng et al. (2011b) considered the $1/ST_{psd}$ problem with deteriorating jobs. They showed that the problem is polynomially solvable with respect to C_{max}, ΣC_j, or $\sum C_j^2$. They also showed that the problem is polynomially solvable with respect to L_{max} or ΣT_j if certain conditions hold. Lai et al. (2011) also addressed the problem of $1/ST_{psd}$ problem with deteriorating jobs. They showed that the problems with the objectives of minimizing C_{max}, ΣC_j are polynomially solvable, and the problems with the objective of minimizing L_{max}, T_{max}, ΣT_j, and $\Sigma w_j C_j$ are solvable under certain conditions.

Wang and Li (2011), Yin et al. (2010b), and Wang et al. (2009b) addressed the problem $1/ST_{psd}$ with the effects of learning and deterioration with different functions. The effects of learning and deterioration imply that the actual processing time of a job depends not only on the processing times of the jobs already processed but also on its scheduled position. All three papers showed that the problems with the performance measures of C_{max}, ΣC_j, $\sum C_j^r$ $(r > 0)$ are polynomially solvable and showed that the problems of L_{max}, $\Sigma w_j C_j$, ΣU_j are polynomially solvable under certain conditions. Furthermore, Toksari et al. (2010) proposed polynomial solutions for the performance measures of C_{max} and $\sum C_j^2$ while Yin et al. (2010a) proposed polynomial solutions with the performance measures of C_{max} and $\sum C_j^r$ $(r > 0)$, and they also proposed polynomial solutions for the problem with the performance measures of L_{max}, $\Sigma w_j C_j$ under certain conditions. Xu et al. (2011) provided a condition that should be satisfied in order for jobs to remain deteriorating for the results obtained by Yin et al. (2010b). Huang (2012) provided a counter example of the result of Yin et al. (2010b) with the performance measure of ΣU_j, Shen et al. (2012) gave a counter example of the result of Yin et al. (2010b) with the performance measure $\Sigma w_j C_j$, Yin et al. (2011a) provided a counter example of the result of Wang et al. (2009b) with the performance measure of ΣU_j while Yin et al. (2011b) provided a counter example of the result of Wang and Li (2011) with the performance measure of ΣU_j. Wang and Wang (2013) considered the $1/ST_{psd}$ problem with general effects of learning and deterioration. They showed that the problem with the performance measures of C_{max}, ΣL_j, $\sum C_j^r$ $(r > 0)$ are polynomially solvable while the problem with the performance measures of L_{max}, T_{max}, ΣT_j, $\Sigma w_j C_j$ remain polynomially solvable under certain conditions. Wang and Wang (2014) considered the $1/ST_{psd}$ problem to minimize C_{max} with jobs ready times and group technology assumption where both job processing times and group setup times are both increasing functions of their starting times. They showed that the problem can be solved in polynomial time. Wang, Dong, Chen, and Lin (2014) also considered the problem, but where the setup time of a group depends on its starting time and the amount of resource allocated. On the other hand, Lee (2014) addressed the problem with the general effects of deterioration and learning.

Yin et al. (2012) addressed the problem of $1/ST_{psd}$ with the effects of learning and deterioration simultaneously, which is a generalization of some existing models in the literature. They showed that the problem with the performance measures of C_{max}, ΣL_j, $\sum C_j^r$ $(r > 0)$, $\Sigma h(E_j)$ with common due date are polynomially solvable while the problems with the performance measures of L_{max}, T_{max}, ΣT_j, $\Sigma w_j h(E_j)$ with common due date, $\Sigma w_j C_j$ are solvable under certain conditions.

Cheng et al. (2010) addressed the $1/ST_{psd}$ problem with deteriorating jobs, learning effect, and proportional setup times, i.e., setup times are proportional to the actual processing times. They showed that the problem is polynomially solvable with respect to C_{max}, ΣC_j, or $\sum C_j^2$. They also showed that the problem is polynomially solvable with respect to L_{max} or ΣT_j if processing times and due dates are agreeable.

Soroush (2012a) addressed the problem of $1/ST_{psd}$ with general job-dependent past-sequence-dependent setup times and learning effects with the objective of minimizing a linear combination of a pair of performance criteria consisting of C_{max}, ΣC_j, and absolute difference in completion times. He provided polynomial solutions for special cases, and proposed a *B&B* algorithm for the general cases. Soroush (2012b) addressed the same problem with the performance measures of C_{max}, ΣL_j, ΣC_j, ΣW_j, *TADC*, sum of earliness, tardiness, and common due date penalty. He showed that special cases are polynomially solvable, and presented *B&B* algorithms for the general cases. Soroush (2014a) considered the problem for stochastic environments where the objective is to minimize a pair of the above mentioned performance measures for the case of job dependent positioned based learning effects where he proposed *B&B* algorithms. Soroush (2014b) provided quadratic assignment problem formulations for the stochastic bicriteria scheduling problem where setup and processing times, and reliabilities/un-reliabilities are sequence-dependent and position dependent random variables.

Huang et al. (2013) addressed the problem of $1/ST_{psd}$ with general time-dependent deterioration and position-dependent learning effect where the actual processing time of a job is not only a non-decreasing function of the total normal processing times of the jobs already processed, but also a non-increasing function of the job's position in the sequence. They showed that the problems with the performance measures of C_{max}, ΣC_j, $\sum C_j^r$ $(r > 0)$ are polynomially solvable while the problem with the performance measures of L_{max} and $\Sigma w_j C_j$ remain polynomially solvable under certain conditions.

Low and Lin (2012) addressed the problem of $1/ST_{psd}$ with a learning effect of family setup times. The actual processing time of a job in each family is a function of the sum of the normal processing times of the jobs already scheduled and the position of the corresponding job family in the sequence. They showed that the problem remains polynomially solvable for the performance measures of C_{max} and ΣC_j. Yin et al. (2013) addressed the problem of $1/ST_{psd}$ with a general learning effect and family setup times. They showed that the problem with the performance measures of C_{max} is polynomially solvable while the problems with the performance measures of ΣC_j and $\Sigma w_j C_j$ are polynomially solvable under certain conditions.

3.5. Other problems with setups

Kacem and Chu (2008) considered the problem of $1/ST_{si}/\Sigma w_jC_j$ with one planned setup period. They proposed two simple *SPT* based heuristics and showed that their worst-case performance ratio is 3.

Wang and Tang (2010) considered the single machine scheduling problem such that each job has a weight (or profit) and there exist sequence-dependent setup times among the jobs. Given that there exists a maximum available time limitation on the machine, it is impossible to complete all the jobs. Hence, the objective is to find a sequence of jobs what maximizes the weights of profit. They modeled the problem as a *MIP* and proposed a hybrid metaheuristic combining scatter search and *VNS*.

Wang et al. (2009a) addressed the single machine scheduling problem with family setup times such that both family setup times and job processing times are increasing functions of their starting times. They showed that the problem remains polynomially solvable with respect to C_{max} performance measure. Wang and Sun (2010) addressed the single machine problem such that family setup times and job processing times are both defined by decreasing function of starting time. They showed that the problem with the C_{max} performance measure remains polynomially solvable while the problem with the performance measure of Σw_jC_j is solvable under certain conditions.

Lu et al. (2014a) considered the problem of $1/ST_{sd}$ where both processing and setup times are uncertain within some intervals. They proposed a local search based heuristic where the objective is to obtain a robust schedule with minimum absolute deviation from the optimal makespan.

Wang and Liu (2014) considered the group scheduling on a single machine with deteriorating setup and processing times where both setup and processing times are increasing function of their starting times. Their primary objective is to minimize Σw_jC_j while the secondary objective is to minimize maximum cost. They presented a polynomial time algorithm. On the other hand, Lu et al. (2014b) addressed the single-machine scheduling problem where group setup times and job processing times are both decreasing functions of their starting times. They indicated that the problem could be solved in polynomial time when the objective is to minimize C_{max} subject to release dates. When the starting times of group setup times and job processing times are linear functions of their starting times, Liu et al. (2014) showed that problem is solvable polynomially when the objective is to minimize C_{max} subject to release dates

Eren (2009a) developed a mathematical programming model for the single machine scheduling problem with learning effects on setup times and removal times where there exists deterioration effect on job processing times.

4. Parallel machines

In a parallel machine environment, all the jobs are required to have a single operation as in the case of a single machine environment. However, the operation can be performed by any of a set of m machines, i.e., the m machines are working in parallel. The m machines may have the same speed, i.e., identical (P); or have different speeds, i.e., uniform (Q); or completely unrelated (R). A summary of the scheduling literature in parallel machine environments is presented in Tables 6 and 7, where the parallel, uniform, or unrelated machines are indicated by the letter P, Q, or R in the third column in the "Comments" area.

4.1. Non-family sequence-dependent setup times (ST_{sd}, SC_{sd})

Different researchers have addressed the problem of $P/ST_{sd}/C_{max}$. Behnamian et al. (2009a) proposed a hybrid algorithm consisting of *ACO*, *SA*, and *VNS*. Hu and Yao (2010) provided two heuristics while Hu and Yao (2011a, 2011b) presented a *MIP* model. Hu and Yao (2011a, 2011b) proposed a *GA*, and introduced a lower bound to evaluate the quality of their proposed *GA*. The heuristics of Hu and Yao (2011a, 2011b) and Behnamian et al. (2009a) have not been compared.

Jairo et al. (2009) proposed a heuristic algorithm, which uses a strategy of random generation of various execution sequences, for the problem of P/ST_{sd}, r_j/C_{max}. Montoya-Torres et al. (2009, 2010) presented a heuristic algorithm for the same problem. They showed that the heuristic performs well by comparing its performance with a lower bound and optimal solution. The heuristics of Jairo et al. (2009) and Montoya-Torres et al. (2010) remain to be compared.

The problem of $R/ST_{sd}/C_{max}$ has been addressed by many researchers. Tran and Christopher Beck (2011) proposed a logic-based-Bender based decomposition approach, which is a combination of MIP and traveling salesman problem, Rabadi et al. (2006) presented a randomized priority search heuristic, Helal et al. (2006) proposed a metaheuristic based on *TS*, and Arnaout et al. (2010) provided an *ACO* algorithm and Arnaout et al. (2014) presented another *ACO* algorithm. Vallada and Ruiz (2011) proposed two versions of the *GA*, including a fast local search and a local search enhanced crossover operator. Vallada and Ruiz (2011) showed that the *GA* performs better than the randomized search heuristic of Rabadi et al. (2006). Ying et al. (2012a) proposed a restricted *SA* algorithm and showed that the restricted *SA* performs much better than the heuristics of Rabadi et al. (2006), Helal et al. (2006), and Arnaout et al. (2010). Niu et al. (2011) proposed an adaptive clonal selection algorithm and showed that their algorithm outperforms *GA* and *SA*. Chang and Chen (2011) derived dominance relations and developed a heuristic from the dominance relations and showed that the heuristic outperforms *SA* and *GA*. They further integrated the dominance relations in *GA* and *SA* and developed meta-heuristics, and showed that the meta-heuristic integrating the dominance relations and *GA* outperforms the others. Cota et al. (2014) proposed a heuristic and Lin and Ying (2014) presented a hybrid artificial bee colony algorithm and compared its performance with those of Chang and Chen (2011) and Ying et al. (2012a). Koh and Mahardini (2014) provided a new *MIP* formulation for the problem and proposed different heuristics, including *GA* while Avalos-Rosales et al. (2015) proposed yet another *MIP* formulation and showed that their new formulation is more effective than the previous ones. Avalos-Rosales et al. (2015) also proposed a metaheuristic algorithm. The heuristics of Lin and Ying (2014), Avalos-Rosales et al. (2015), Arnaout et al. (2014), and Niu et al. (2011) are not compared.

Liu et al. (2011) presented an *ACO* for the problem of R/ST_{sd}, $prec/C_{max}$. Hou and Guo (2013) addressed the problem of $R/ST_{sd}/C_{max}$ with multiple resource constraints. They provided a *MIP* model and presented a *GA* for large size problems. On the other hand, Rambod and Rezaeian (2014) proposed a metaheuristic, including *GA* and bee algorithms, for the problem of $R/ST_{sd}/C_{max}$ with machine eligibility and the probability that some jobs may need rework.

Li and Milne (2014) proposed a three-step heuristic algorithm for the problem of $R/SC_{sd}/TSC$. They showed that the algorithm performs well when applied to a chemical company.

Lee et al. (2010) presented a lower bound for the problem of P/ST_{sd}, r_j/L_{max} and proposed a restricted *SA* which incorporates a restricted search strategy. They showed that their restricted *SA* performs better than only *SA* and the existing algorithms. Ying and Cheng (2010) presented an iterated greedy heuristic for the same problem and showed that it performs better than earlier existing solutions. The heuristics of Lee et al. (2010) and Ying and Cheng (2010) have not been compared.

Gacias et al. (2010) addressed the problems of P/ST_{sd}, r_j, $prec/\Sigma C_j$ and P/ST_{sd}, r_j, $prec/L_{max}$. For each problem, they provided some dominance relations and presented a *B&B* algorithm. Moreover, they proposed heuristics based on climbing discrepancy search methods.

Fan and Tang (2006) developed an integer programming model for the problem of $P/ST_{sd}/\Sigma w_jC_j$. They also presented a column generation algorithm for the problem and showed that the column generation algorithm can solve problems up to 10 machines and 60 jobs in

Table 6
Parallel machines non-family setup time scheduling problems (ST_{sd}, SC_{sd}).

Setup type	References	Criterion (machine type [P,Q, or R], comments)	Approach
ST_{sd}	Akyol and Bayhan (2008)	$\Sigma(w_{j1}E_j+w_{j2}T_j)$ (R)	MIP model, artificial neural network
	Anderson et al. (2013)	$\Sigma(E_j+T_j)$ (P)	Network-based MIP model
	Andrés and Ruiz (2007)	F_l (ΣC_j, *total # of assigned resources*) (*R, resource constraint*)	*MIP* model, fast dispatching heuristics
	Aramon Bajestani and Tavakkoli-M. (2009)	Σw_jT_j (R)	*B&B* algorithm utilizing two dominance relations
	Arango et al. (2013)	ΣT_j (*R, prec, dynamic job arrivals*)	*GA*
	Armentano and de Franca Filho (2007)	ΣT_j (Q)	Memory-based *GRASP*
	Arnaout et al. (2010, 2014)	C_{max} (R)	*ACO*
	Avalos-Rosales et al. (2015)	C_{max} (*R setup times machine dependent*)	*MIP*, Metaheuristic
	Behnamian et al. (2009a)	C_{max} (P)	Hybrid algorithm consisting of *ACO*, *SA*, and *VNS*
	Behnamian et al. (2009c)	$\Sigma(E_j+T_j)$ (P)	Three metaheuristics based on *SA*, *ACO*, and *VNS*
	Behnamian et al. (2010a)	$\#(C_{max}, \Sigma(E_j+T_j))$ (P)	Multi-phase covering Pareto-optimal front method
	Behnamian et al. (2011a)	$\#(C_{max}, \Sigma(E_j+T_j))$ (P)	*ACO*, *SA*, *VNS*
	Caniyilmaz et al. (2015)	F_l (C_{max}, ΣT_j) (R)	A metaheuristic integrating ABC and GA
	Cevikcan et al. (2011)	*TST*	Expert system
	Chang and Chen (2011)	C_{max} (R)	Dominance relations, *GA*, *SA*, meta-heuristics
	Chen (2009a)	ΣT_j (*R, setup times machine dependent*)	*SA*, two other heuristics
	Chen and Chen (2009)	Σw_jU_j (R)	*TS*, metaheuristics
	Chyu and Chang (2010)	$\#(\Sigma w_jF_j, \Sigma w_jT_j)$ (*R, setup times machine dependent*)	Pareto evolutionary approach
	Cota et al. (2014)	C_{max} (R)	Heuristic based on ILS, path relinking, and variable neighborhood descent
	de Paula et al. (2010)	Σw_jT_j (R)	Non-delayed relax-and-cut algorithm, Lagrangian heuristic
	Dinh and Bae (2012)	F_l (ΣT_j, *TST*) (*P, dynamic sequence-dependent setup times*)	*MIP* model
	Driessel and Mönch (2009)	Σw_jT_j (*P*, r_j, *prec*)	*VNS*
	Driessel and Mönch (2011)	Σw_jT_j (*P*, r_j, *prec*)	Several variants of *VNS* schemes
	Fan and Tang (2006)	Σw_jC_j (P)	Integer programming model, a column generation algorithm
	Gacias et al. (2010)	ΣC_j (*P*, r_j, *prec*)	Dominance relations, *B&B* algorithm, heuristics based on climbing discrepancy search methods
	Gacias et al. (2010)	L_{max} (*P*, r_j, *prec*)	Dominance relations, *B&B* algorithm, heuristics based on climbing discrepancy search methods
	Gharehgozli et al. (2009)	*GP*(Σw_jT_j *and* Σw_jF_j) (*P*, r_j, *fuzzy processing times*)	Mixed integer goal programming model
	Gokhale and Mathirajan (2012)	Σw_jF_j (*P*, r_j, *machine eligibility*)	Mathematical model, heuristic algorithms
	Helal et al. (2006)	C_{max} (R)	*TS*
	Hou and Guo (2013)	C_{max} (*P, multiple resource constraints*)	*MIP*, *GA*
	Hu and Yao (2010)	C_{max} (P)	Two versions of *GA*
	Hu and Yao (2011a)	C_{max} (P)	*MIP* model, lower bound, *GA*
	Hu and Yao (2011b)	C_{max} (P)	*MIP* model, lower bound, *GA*
	Jairo et al. (2009)	C_{max} (*P*, r_j)	Heuristic
	Joo and Kim (2012)	*Weighted sum of setup times, delay times, tardy times* (r_j)	*MIP* model, *GA*, self-evolution algorithm
	Kampke et al. (2009)	F_l (ΣC_j, *total # of assigned resources*) (*R, setup times machine dependent*)	*GRASP*
	Kang et al. (2007)	Σw_jT_j (*P*, r_j, *rework flows*)	Rolling horizon *TS*
	Kang and Shin (2010)	ΣT_j, ΣF_j, ΣL_j, ΣU_j, *number of reworks* (*P, rework probabilities*)	Heuristics based on dispatching rules
	Kim et al. (2006)	ΣT_j (*P*, r_j)	*TS*
	Koh and Mahardini (2014)	C_{max} (*R setup times machine dependent*)	Heuristics, GA
	Lee et al. (2010)	L_{max} (*P*, r_j)	Lower bound, a restricted *SA*
	Lee et al. (2013)	ΣT_j (*R, setup times machine dependent*)	*TS*
	Li et al. (2012a,b)	*GP*(C_{max},ΣT_j)(*P*, r_j)	*MILP*, metaheuristics based on *GA*
	Lin and Ying (2014)	C_{max} (R)	A hybrid artificial bee colony algorithm
	Lin et al. (2011b)	ΣT_j (*R, setup times machine dependent*)	Iterated greedy algorithm
	Lin and Hsieh (2014)	Σw_jT_j (*R*, r_j, *setup times machine dependent*)	*MIP* model, an iterated hybrid metaheuristic
	Liu et al. (2011)	C_{max} (*R, prec*)	*ACO*
	Logendran et al. (2007)	Σw_jT_j (*R, dynamic job arrivals*)	Dispatching rules, different search algorithms based on *TS*
	Montoya-Torres et al. (2009)	C_{max} (*P*, r_j)	Heuristic algorithm
	Montoya-Torres et al. (2010)	C_{max} (*P*, r_j)	Heuristic algorithm
	Naderi-Beni et al. (2014)	*GP*(*Work imbalance*, ΣT_j) (*P*, r_j)	Fuzzy MILP and metaheuristics
	Niu et al. (2011)	C_{max} (R)	Adaptive clonal selection algorithm
	Park and Seo (2012)	*Maximize the work balance among transporters* (P)	*GRASP*
	Park and Seo (2013)	*Maximize the work balance among transporters*, C_{max} (P)	*GRASP*
	Pereira Lopes and de Carvalho (2007)	Σw_jT_j (*R*, r_j, *machine availability*)	Branch-and-price algorithm
	Pfund et al. (2008)	Σw_jT_j (*P*, r_j)	Heuristic based on apparent tardiness cost with setups approach
	Rabadi et al. (2006)	C_{max} (R)	Randomized priority search heuristic
	Rambod and Rezaeian (2014)	C_{max} (*R, job rework, machine eligibility*)	Metaheuristic including GA and bee algorithms
	Ribas-Vila et al. (2009)	F_l (ΣC_j, ΣT_j) (P)	Six simple heuristics
	Rocha et al. (2008)	F_l (C_{max}, Σw_jT_j) (*R, setup times machine dependent*)	*MIP*, *B&B* algorithm
	Tavakkoli-Moghaddam et al. (2008)	*Lex* (ΣC_j, ΣU_j) (*R*, r_j, *prec*)	*MIP*
	Tavakkoli-Moghaddam et al. (2009)	*Lex*(ΣC_j, ΣU_j) (*R*, r_j, *prec*)	*MIP* based on goal programming, *GA*

(continued on next page)

Table 6 (*continued*)

Setup type	References	Criterion (machine type [P,Q, or R], comments)	Approach
	Toksari and Guner (2010)	$\Sigma(w_{j1}E_j+w_{j2}T_j)$ (*P, effects of learning and deterioration*)	*MIP*
	Torabi et al. (2013)	$\#(\Sigma w_jF_j, \Sigma w_jT_j$, *total machine load*)(*R*, r_j, *uncertain processing times and due dates*)	Multi-objective *PSO*
	Tran and Christopher Beck (2011)	C_{max} (*R, setup times machine dependent*)	Logic-based-Bender decomposition approach
	Tsai and Tseng (2007)	Σw_jC_j (*R, resource constraint*)	*MIP* model, *GA*
	Vallada and Ruiz (2011)	C_{max} (*R*)	Two versions of *GA*
	Wang et al. (2013)	F_l (Σw_jU_j, C_{max}) (*R*, r_j)	*MIP*, local search heuristic
	Xi and Jang (2012)	Σw_jT_j (*P*, r_j)	Dispatching rules
	Ying and Cheng (2010)	L_{max} (*P*, r_j)	Iterated greedy heuristic
	Ying and Lin (2012)	ΣT_j (*R, setup times machine dependent*)	Artificial bee colony algorithm
	Ying et al. (2012a)	C_{max} (*R*)	Restricted *SA* algorithm
	Zhang et al. (2007)	Σw_jT_j (*R*, r_j)	Q-learning algorithm, simple heuristics
SC_{sd}	Li and Milne (2014)	*TSC* (*R*)	A three step heuristic algorithm

Table 7
Parallel machines family setup time scheduling problems ($ST_{si,f}$, $ST_{sd,f}$, $SC_{sd,f}$).

Setup type	References	Criterion (comments)	Approach
$ST_{si,f}$	Bettayeb et al. (2008)	Σw_jC_j	Lower bounds, *B&B* algorithm, constructive heuristic
	Schaller (2014)	$\Sigma T_j(P)$	*TS*, *GA*
	Tavakkoli-Moghaddam and Mehdizadeh (2007)	Σw_jF_j	Integer linear programming, *GA*
$ST_{sd,f}$	Bozorgirad and Logendran (2012)	F_l (Σw_jC_j, Σw_jT_j) (*R*, r_j)	*MILP*, meta-heuristics based on *TS*
	Chung et al. (2009)	*Total profit subject to fulfilling contracted quantity*	Two new algorithms
$SC_{sd,f}$	Loveland et al. (2007)	*TSC*	Algorithm combining optimization and heuristic components
	Monkman et al. (2008)	*TSC*	*GRASP*
	Park et al. (2012)	ΣT_j (*non-family sequence independent setup times*)	Heuristic algorithm

reasonable time. Tsai and Tseng (2007) presented a *MIP* model, with discrete time assumption, for the problem of $R/ST_{sd}/\Sigma w_jC_j$ which can be used for small size problems. They also presented a *GA* for larger size problems.

Pfund et al. (2008) presented a heuristic, based on apparent tardiness cost with setups approach for the problem of $P/ST_{sd}, r_j/\Sigma w_jT_j$. Xi and Jang (2012) addressed the same problem by considering setup times into two categories based on whether or not the setup of the next selected future job is allowed to start when a machine becomes idle, even before the next job is ready to be processed. They called these two categories as continuous and separable. For both categories, they showed by computational experiments that modified apparent tardiness cost with setup and ready time and apparent tardiness cost with separable setup and ready time outperform other existing *ATC*-based rules.

Kim et al. (2006) proposed a *TS* algorithm for the problem of $P/ST_{sd}, r_j/\Sigma T_j$ and showed that the *TS* outperforms the earlier existing solution. Driessel and Mönch (2009) proposed a *VNS* scheme while Driessel and Mönch (2011) presented several variants of *VNS* schemes for the problem of $P/ST_{sd}, r_j, prec/\Sigma w_jT_j$ and showed that the models perform much better than some dispatching rules.

Kang et al. (2007) addressed the problem of $P/ST_{sd}, r_j/\Sigma w_jT_j$ with rework flows. They proposed a three phase heuristic where the third phase is a rolling horizon *TS*.

Armentano and de Franca Filho (2007) presented a memory-based *GRASP* for the problem of $Q/ST_{sd}/\Sigma T_j$ and showed that their procedure outperforms the heuristics from the literature.

Chen (2009a) presented an SA algorithm and two other heuristics, apparent-tardiness-cost-with-setup procedure and designed improvement procedure, for the problem of $R/ST_{sd}/\Sigma T_j$ with due date constraints where setup times are also machine dependent. He showed by extensive computational experiments that the *SA* performs much better than the other two heuristics. Lin et al. (2011b) proposed an iterated greedy algorithm while Ying and Lin (2012) proposed an artificial bee colony algorithm for the same problem. Lee et al. (2013) proposed a *TS* algorithm which incorporates variable neighborhood generation methods and showed that their *TS* algorithm outperforms the *SA* of Chen (2009a) and the iterated greedy algorithm of Lin et al. (2011b). The heuristics of Ying and Lin (2012) and Lee et al. (2013) remain to be compared.

de Paula et al. (2010) presented a non-delayed relax-and-cut algorithm for the problem of $R/ST_{sd}/\Sigma w_jT_j$, a real case of a particular plant of a refractory brick factory. They also proposed a Lagrangian heuristic for obtaining approximate solutions. They were able to obtain optimal solutions for problems up to 180 jobs and 6 machines by using their proposed solution. Two dominance relations were developed by Aramon Bajestani and Tavakkoli-Moghaddam (2009) for the same problem. They also presented a B&B algorithm which integrates the two dominance relations.

Zhang et al. (2007) presented five simple heuristics for the problem of $R/ST_{sd}, r_j/\Sigma w_jT_j$ where a given job can be processed by a subset of the available parallel unrelated machines. They also presented a Q-learning algorithm and showed that the algorithm performs better than the five heuristics. Lin and Hsieh (2014) proposed a *MIP* model for the problem of $R/ST_{sd}, r_j/\Sigma w_jT_j$ where setup times also depend on machines. They also presented an iterated hybrid metaheuristic integrating *EMA* algorithm and local search. They showed that the heuristic performs better than *TS* and *ACO* algorithms which were presented earlier in the literature for related problems. Pereira Lopes and de Carvalho (2007) proposed a branch-and-price algorithm for the same problem with the restriction of availability dates for machines.

Logendran et al. (2007) provided four different dispatching rules for the problem of $R/ST_{sd}/\Sigma w_jT_j$ with dynamic job arrivals. They also presented different search algorithms based on *TS* and evaluated them. Arango, Giraldo, and Castrillón (2013) proposed a GA for the problem of $R/ST_{sd}, prec/\Sigma T_j$ for the case of dynamic job arrivals.

Behnamian et al. (2009c) presented three metaheuristics, based on *SA*, *ACO*, and *VNS*, for the problem of $P/ST_{sd}/\Sigma(E_j + T_j)$ where the jobs have due windows. They showed that the heuristic based on *SA*, *ACO*, and *VNS* perform better than the one based on *SA* and *VNS* and the one based on *ACO* and *VNS*. Anderson et al. (2013) proposed a network based *MIP* formulation model for the problem of $P/ST_{sd}/\Sigma(E_j + T_j)$. They showed that their *MIP* model is more efficient than the earlier existing models in terms of computational time for large problems. Anderson (2014) corrected an error in the earlier provided mathematical modeling formulation for the problem.

An *MIP* model for the problem of $R/ST_{sd}/\Sigma(w_{j1}E_j + w_{j2}T_j)$ was presented by Akyol and Bayhan (2008). They also presented an artificial neural network to solve the problem. Chen and Chen (2009) presented several metaheuristics, including *TS* and variable neighborhood decent approach, for the problem of $R/ST_{sd}/\Sigma w_jU_j$. They showed that the metaheuristics perform much better than basic *TS*.

Gokhale and Mathirajan (2012) provided a mathematical formulation for the problem of (2012) $P/ST_{sd}, r_j/\Sigma w_jF_j$ with the constraint of machine eligibility. They also provided a few heuristic algorithms.

Cevikcan et al. (2011) developed an expert system for the problem of $P/ST_{sd}/TST$ and showed that setup times are reduced by about 7 percent if the developed system is utilized compared with the currently used system.

Dinh and Bae (2012) addressed the problem of $P//F_l$ $(\Sigma T_j, TST)$ where setup times between two jobs not only depends on their sequence, but also on the previous sequences. They transformed the problem into a multi-depot multiple asymmetric travelling salesman problem and presented a *MIP* model.

Park and Seo (2012) considered the problem of $P/ST_{sd}, prec$ with the objective of maximizing the work balance among transporters. Park and Seo (2013) also addressed the same problem with an additional performance measure of C_{max}. Park and Seo (2013) proposed a *GRASP* heuristic and compared its performance with the optimal solution using *B&B* algorithm for small size problems. They also compared its performance with centralized and decentralized heuristics and showed that the *GRASP* outperforms the other heuristics.

Kang and Shin (2010) addressed the problem of $P/ST_{sd}/\Sigma T_j$, ΣF_j, ΣL_j, ΣU_j, *number of reworks* with rework probabilities. They developed two heuristics based on dispatching rules and problem-space-based search method.

Ribas-Vila et al. (2009) presented and evaluated six simple heuristic algorithms for the problem of $P/ST_{sd}/F_l$ $(\Sigma C_j, \Sigma T_j)$. Joo and Kim (2012) presented a *MIP* model for the problem of $P/ST_{sd}, r_j$ with the objective of minimizing a weighted sum of setup times, delay times, and tardy times. They also proposed a *GA*, and a self-evolution algorithm and showed that the self-evolution algorithm performs much better.

Andrés and Ruiz (2007) addressed the problem of $R/ST_{sd}/F_l$ (ΣC_j, *total # of resource assigned*) where the amount of setup time not only depends on the machine and job sequence, but also on the number of resources assigned, which can vary between a minimum and a maximum. They presented a *MIP* model and proposed several fast dispatching heuristics. Kampke et al. (2009) proposed a *GRASP* based metaheuristic while Kampke et al. (2010) presented a new *ILS* heuristic and they showed that their *GRASP* based metaheuristic and *ILS* heuristic improve the best known results from the literature by a significant margin.

Rocha et al. (2008) presented two *MIP* models and a *B&B* algorithm for the problem of $R/ST_{sd}/F_l$ $(C_{max}, \Sigma w_jT_j)$ where setup times are machine dependent while Caniyilmaz et al. (2015) presented a metaheuristic integrating a swarm-intelligence-based (called *ABC*) algorithm and *GA* for the problem of $R/ST_{sd}/F_l$ $(C_{max}, \Sigma T_j)$. Wang et al. (2013) formulated the problem of $R/ST_{sd}, r_j/F_l$ $(\Sigma w_jU_j, C_{max})$ as an *MIP* and proposed a local search heuristic to solve larger size problems.

Tavakkoli-Moghaddam et al. (2008) presented a *MIP* model, based on goal programming, for the problem of $R/ST_{sd}, r_j, prec/Lex(\Sigma U_j, \Sigma C_j)$. On the other hand, Tavakkoli-Moghaddam et al. (2009) presented a *GA* for the same problem.

Gharehgozli et al. (2009) presented a mixed integer goal programming model for the problem of $P/ST_{sd}, r_j/GP(\Sigma w_jT_j, \Sigma w_jF_j)$ where processing times are considered to be fuzzy. Naderi-Beni et al. (2014) proposed a fuzzy bi-objective *MILP* formulation and presented two metaheuristic algorithms for the problem of $P/ST_{sd}, r_j/GP(\Sigma T_j$, *work imbalance*) where setup and processing times and release and due dates were considered to be fuzzy, i.e., uncertain.

Behnamian et al. (2010a, 2011a) addressed the problem of $P/ST_{sd}/\#(C_{max}, \Sigma(E_j + T_j))$ with due windows for jobs, i.e., each job has interval rather than a single value. Behnamian et al. (2010a) proposed a multi-phase covering Pareto-optimal front method by using a multi-phase algorithm iterating over a *GA* in the first phase and three hybrid metaheuristics in the second and third phases. They showed that the multi-phase method is a better tool to approximate the efficient set than the global archive sub-population *GA* presented previously. Behnamian et al. (2011a) proposed a Pareto-optimal front method by using hybrid metaheuristics and weighted min–max technique by using an *ACO*, *SA*, and *VNS*.

Li et al. (2012a, 2012b) presented a *MILP* model for the problem of $P/ST_{sd}, r_j/GP(C_{max}, \Sigma T_j)$. They also proposed two metaheuristics; a non-dominated sorting *GA* and a fuzzy logic controlled coupled with the non-dominated sorting *GA*. They showed that the fuzzy logic controlled metaheuristic outperforms the other.

Chyu and Chang (2010) presented a Pareto evolutionary approach to the problem of $R/ST_{sd}/\#(\Sigma w_jF_j, \Sigma w_jT_j)$. They showed that the Pareto evolutionary approach performs better than two multi-objective *SA* algorithms. Torabi et al. (2013) presented a multi-objective *PSO* algorithm for the problem of $R/ST_{sd}, r_j/\#(\Sigma w_jF_j, \Sigma w_jT_j$, *total machine load*) where processing times and job due dates are uncertain.

Toksari and Guner (2010) presented a *MIP* formulation for the problem of $P/ST_{sd}/\Sigma(w_{j1}E_j+w_{j2}T_j)$ with simultaneous effects of learning and linear deterioration. They also showed that the optimal solution for this problem is *V*-shaped.

4.2. Family sequence-independent setup times ($ST_{si,f}$)

Schaller (2014) proposed different versions of *TS* and *GA* algorithms for the problem of $P/ST_{si,f}/\Sigma T_j$. They showed that *GA* algorithms perform better than the *TS* algorithms.

Tavakkoli-Moghaddam and Mehdizadeh (2007) presented an integer linear programming model for the problem of $P/ST_{si,f}/\Sigma w_jF_j$. They also proposed a *GA* for solving large size problems.

Bettayeb et al. (2008) provided three lower bounds and a constructive heuristic for the problem of $P/ST_{si,f}/\Sigma w_jC_j$. They also proposed a *B&B* algorithm which incorporates the lower bounds. The computational experiments indicated that the algorithm is effective.

4.3. Family sequence-dependent setup times/setup costs ($ST_{si,f}$, $SC_{si,f}$)

Loveland et al. (2007) presented an algorithm combining both optimization and heuristic components for the manufacturing of Dell Inc. which could be modeled as $P/SC_{sd,f}/TSC$. By using the algorithm, an effective production volume increased as much as 35 percent. As a result, Dell Inc. has saved over $1 million per year by implementing their algorithm. Monkman et al. (2008) considered the same problem where they proposed a *GRASP* algorithm. They showed that an additional reduction of 14–21 percent in cost is achieved by using *GRASP* over the algorithm of Loveland et al. (2007).

Park et al. (2012) considered the problem of $P/SC_{sd,f}/\Sigma T_j$ such that jobs also have sequence independent setup times, called minor setup times, where jobs are allowed to be split such that the parts of the splitting jobs can be processed by different machines. They presented a job splitting and setup times based heuristic for the problem.

Chung et al. (2009) addressed the problem of $P/ST_{sd,f}$ with the objective of maximizing total profit subject to the constraint that contracted quantities should be fulfilled. They proposed two new algorithms and showed that they are indeed efficient.

Bozorgirad and Logendran (2012) addressed the problem of $R/ST_{sd,f}$, r_j/F_l $(\Sigma w_jC_j, \Sigma w_jT_j)$. They presented an *MILP* model and proposed meta-heuristics based on *TS*. They showed that their meta-heuristics perform well by comparing the performance with the optimal solution for small size problems.

4.4. Other problems with setup times

Hsu et al. (2011) developed a polynomial time solution for the unrelated parallel machine scheduling problem with past-sequence-dependent setup times and learning effects with the objective of minimizing ΣC_j. They also addressed two special cases of the problem. Kuo, Hsu, and Yang (2011) addressed the same problem with respect to *TADC* and total loads on machines, and they showed that the problem is polynomially solvable.

Eren (2009b) developed a mathematical programming model and presented three insertions based heuristics for the parallel machine scheduling problem to minimize $\Sigma C_j + \Sigma T_j$ with setup times and removal times where there exist learning effect on setup times and removal times. A correction in the mathematical programming model of Eren (2009b) was proposed by Xu and Yin (2011b).

Yang, Hsu, and Yang (2010) considered the problem of unrelated parallel machine with learning effects on processing times, setup times, and removal times. They showed that the problem with the performance measures of ΣC_j, total load, and total absolute deviation of job completion times are solvable under certain conditions.

Amini, Tavakkoli-Moghaddam, and Niakan (2011) addressed the parallel machine scheduling problem when there are position-based deteriorating jobs with setup and removal times that are affected by the position-based learning effect. The objective was to minimize the sum of $\Sigma(E_j + T_j)$, ΣU_j, and ΣC_j. A mathematical model was developed and some heuristics were proposed and compared.

Ruiz and Andrés-Romano (2011) addressed the problem of R/ST_{sd} such that setup times depend on both machine and the amount of resources assigned. The performance measure is a linear combination of ΣC_j and the total amount of resources assigned. They presented a *MIP* model and proposed fast dispatching heuristics. Bicalho, Dos Santos, and Arroyo (2011) presented two metaheuristic algorithms utilizing *GRASP* and *TS* for the same problem.

Lee et al. (2012a) addressed the parallel machine scheduling problem with history-dependent setup times where the duration of a setup operation does not depend only on the job that just has been completed but on a number of preceding jobs. They considered multiple objectives and presented pseudo-polynomial time algorithms for some of the problems.

Pessan, Neron, and Haouari (2013) considered the problem of scheduling operations within a production resetting that arises at the ball bearing factories. They showed that the problem can be can be modelled as an unrelated parallel machine scheduling problem with setup times. They proposed two lower bounds to minimize C_{max}. They indicated that the bounds are efficient.

Freeman et al. (2014) developed an *MIP* formulation for the problem of non-identical parallel machine with ST_{sd} and SC_{sd} to capture trade-offs between overtime and labor costs and waste costs. They also developed two procedures.

5. Flowshops

We classify flowshop scheduling problems as; flowshop, no-wait flowshop, flexible flowshop, and assembly flowshop. There are m stages in series in an m-machine flowshop environment. Each job has to be processed in each of the m stages in the same order. Operation times for each job in different stages usually are different. There exists only one machine at each stage in an m-machine flowshop while there is more than one machine in at least one of the stages, as a result of the need to increase the capacity in that stage, in an m-machine flexible (or hybrid) flowshop. In a no-wait flowshop, a succeeding operation starts immediately after the preceding operation is completed. In a two stage assembly flowshop, each job consists of k specific operations, where the first $k - 1$ operations have to be performed on a pre-determined set of $k - 1$ machines, working in parallel, of the first stage, and the last operation k (the assembly operation) has to be performed on the second stage machine. It should be noted that flowshops are permutation flowshops, the same job sequence in each stage, unless stated as non-permutation where each stage may not have to have the same job sequence.

Filho et al. (2013) provided a survey on flowshop scheduling problems with sequence-dependent setup times by covering 83 papers, the majority of which were covered by Allahverdi et al. (1999, 2008). Therefore, what Filho et al. (2013) covered is just a small subset of what has been covered in this section since both sequence-dependent and sequence-independent problems are covered in this paper. Moreover, not only regular flowshops but also no-wait flowshop, flexible flowshop, and assembly flowshop are considered in this paper. The results for $F2$ are presented before those for Fm. Similarly, the results for $FF2$ are discussed before those for FFm.

A summary of the scheduling literature on flowshop scheduling in the environments of non-family and family setup times is presented in Tables 8 and 9, respectively.

5.1. Non-family sequence-independent setup times (ST_{si})

The results for each of the regular flowshop, no-wait flowshop, flexible flowshop, assembly flowshop, and uncertain environments are presented in the subsequent subsections, respectively.

5.1.1. Flowshop

Wang and Cheng (2007a) proposed a polynomial approximation scheme for the problem of $F2/ST_{si}/C_{max}$ when there is an availability constraint on the first machine. Wang and Cheng (2007b) considered the same problem but where the availability constraint is on one of the two machines. They presented two heuristics.

Yang and Liu (2008) presented a multi-objective *GA* with local search for the problem of $Fm/ST_{si}/F_l$ (C_{max}, T_{max}). They showed that their multi-objective algorithm outperforms two other multi-objective GAs in the literature.

Xu and Yin (2011c) proposed a corrected integer programming model that was proposed by Eren and Güner (2006) for the problem of $F2/ST_{si}/F_l$ (ΣC_j, ΣT_j) was incorrect.

Eren (2007) developed an integer programming model and presented heuristics based on *TS* and random search for the problem of $F2/ST_{si}/F_l$ (ΣC_j, C_{max}, T_{max}, E_{max}). He showed that the heuristic based on *TS* performs better than those based on a random search.

Msakni, Ladhari, and Allahverdi (2009) presented a constructive heuristic and Ladhari et al. (2012) proposed a new priority rule for the problem of $F2/ST_{si}/\Sigma C_j$. Ladhari et al. (2012) also proposed several constructive heuristics, local search procedures, and a multiple crossover *GA*. They showed that one of the constructive heuristics performs better than the best existing constructive heuristics in the literature, and also showed that one of the local search procedures performs better than the best existing local search procedure. Gharbi et al. (2013) proposed several new bounds for the problem of $Fm/ST_{si}/\Sigma C_j$ and utilized these bounds in a *B&B* algorithm. They showed that their new bounds outperform the earlier existing bounds significantly.

Agrawal et al. (2012) considered the problem of $F3/ST_{si}/\Sigma C_j$ with transportation times, and start and stop lags. They presented an algorithm which finds the optimal solution for small size problems.

5.1.2. No-wait flowshop

Chang and Shao (2006) proposed an optimal property for the problem of $F3/ST_{si}$, *no-wait*$/\Sigma F_j$. They also presented two heuristics which can be used for large size problems.

Table 8
Flow shop non-family setup time scheduling problems (ST_{si}, ST_{sd}).

Setup type	References	# of stages (type)	Criterion (comments)	Approach
ST_{si}	Agrawal et al. (2012)	3 (*transportation times, start and stop lags*)	ΣC_j	Algorithm for small size problems
	Aldowaisan and Allahverdi (2015)	*m*(*no-wait*)	ΣT_j	Improved versions of *SA* and *GA* algorithms
	Allahverdi (2007)	3	ΣC_j	Dominance relations
	Allahverdi (2008)	3	C_{max} (*uncertain setup and processing times*)	Dominance relations
	Allahverdi (2009)	3	L_{max} (*uncertain setup and processing times*)	Dominance relations
	Allahverdi et al. (2015)	2 (*assembly flowshop*)	ΣT_j	Dominance relations, SA, GA, insertion algorithm
	Allahverdi and Al-Anzi (2008)	2 (*assembly flowshop*)	ΣC_j	Dominance relations
	Allahverdi and Al-Anzi (2009)	2 (*assembly flowshop*)	ΣC_j	Hybrid *TS*, self-adaptive DE
	Allahverdi and Aydilek (2014)	*m* (*no-wait*)	$\in(\Sigma C_j/C_{max})$	Heuristics; *SA*, GA, DE, insertion
	Aydilek and Allahverdi (2013)	2	C_{max} (*uncertain processing times*)	Polynomial time heuristics
	Aydilek et al. (2013)	2	C_{max} (*uncertain setup times*)	Polynomial time heuristics
	Aydilek et al. (2015a)	2	C_{max} (uncertain setup and processing times)	Polynomial time heuristics
	Aydilek et al. (2015b)	2 (*assembly flowshop*)	T_{max}	Dominance relations, heuristics
	Azadeh et al. (2012)	2 (*assembly flowshop, random setup and processing times*)	F_l (ΣC_j, C_{max})	Integrated simulation and artificial neural network
	Chang and Shao (2006)	3 (*no-wait*)	ΣF_j	Optimal property, heuristic
	Fattahi et al. (2014)	2 (*flexible, assembly operation*)	C_{max}	Lower bounds, *B&B* algorithm
	Eren (2007)	2	F_l (ΣC_j, C_{max}, T_{max}, E_{max})	Heuristics based on *TS* and random search, integer programming model
	Eren and Güner (2006)	2	F_l (ΣC_j, ΣT_j)	Integer programming model
	Gharbi et al. (2013)	2	ΣC_j	Lower bounds, *B&B* algorithm, Lagrangian relaxation
	Gupta et al. (2013)	2	C_{max} (*fuzzy setup and processing times, transportation*) *time*)	Algorithm
	Huang et al. (2009)	2 (*flexible, no-wait*)	ΣC_j	Integer programming, *ACO*
	Ladhari et al. (2012)	2	ΣC_j	Constructive heuristics, local search procedures, *GA*
	Lo et al. (2008)	2 (*flexible*)	C_{max}	*B&B* algorithm, *GA*
	Nagano et al. (2012)	*m*(*no-wait*)	ΣC_j	A new evolutionary clustering search heuristic
	Tian et al. (2013)	2 (*assembly flowshop*)	F_l (ΣC_j, C_{max})	Discrete *PSO*
	Wang and Cheng (2007a)	2	C_{max} (*availability constraint on the first machine*)	Polynomial approximation scheme
	Wang and Cheng (2007b)	2	C_{max} (*availability constraint on one of the machines*)	Heuristics
	Xu and Yin (2011c)	2	F_l (ΣC_j, ΣT_j)	Integer programming model
	Yang and Liu (2008)	*m*	F_l (C_{max}, T_{max})	Multi-objective *GA* with local search
ST_{sd}	Abiri et al. (2009)	*m* (*flexible*)	C_{max}	*TS*
	Abyaneh and Zandieh (2012)	*m* (*flexible, buffer*)	$\#(C_{max}, \Sigma T_j)$	*GA*
	Alem Tabriz et al. (2009)	*m* (*flexible*)	C_{max}	*SA*
	Amin-Tahmasbi and Tavakkoli-Moghaddam (2011)	*m*	$\#(\Sigma C_j, \Sigma(Ej+T_j))$	Mathematical modeling, multi-objective immune system
	Arabameri and Salmasi (2013)	*m* (*no-wait*)	$\Sigma(w_{1j}E_j+w_{2j}T_j)$	*TS* and *PSO*
	Asefi et al. (2014)	*m* (*flexible, no-wait*)	$\#(C_{max}, \Sigma T_j)$	Metaheuristic
	Behnamian (2014a)	*m* (*flexible*)	$\#(C_{max}, \Sigma(E_j+T_j))$	Parallel algorithms
	Behnamian (2014b)	*m* (*flexible*)	F_l (C_{max}, ΣE_j, ΣT_j, *# of worker employed*)	Colonial competitive algorithm
	Behnamian et al. (2009b)	*m* (*flexible*)	$\#(C_{max}, \Sigma(E_j+T_j))$	Multi-phase covering Pareto-optimal front method
	Behnamian et al. (2010b)	*m* (*flexible*)	$\Sigma(E_j+T_j)$	Hybrid metaheuristic algorithm
	Behnamian et al. (2011b)	*m* (*flexible*)	$\#(C_{max}, \Sigma(E_j+T_j))$	A hybrid metaheuristic consisting of *ACO*, *SA*, and *VNS*
	Behnamian and Ghomi (2011)	*m* (*flexible, unrelated parallel machines*)	$\#(C_{max}$ *and total recourse allocation cost*)	Hybrid metaheuristic algorithm
	Behnamian and Ghomi (2014)	*m* (*flexible, fuzzy setup times and due dates*)	$\#(C_{max}, \Sigma(E_j+T_j))$	*PSO*
	Behnamian et al. (2014)	*m* (*flexible*)	$\#(C_{max}, \Sigma(E_j+T_j))$	Heuristic consisting of *PSO*, *TS*, *VNS*
	Behnamian and Zandieh (2011)	*m* (*flexible*)	$\sum (E_j + T_j^2)$	*MIP*, colonial competitive algorithm
	Behnamian et al. (2012)	*m* (*flexible*)	C_{max}	Hybrid metaheuristic algorithm
	Behnamian and Zandieh (2013)	*m* (*flexible, learning effect*)	$\Sigma(E_j+T_j)$	Hybrid metaheuristic; *PSO*, *SA*, *VNS*
	Dalfar et al. (2012)	2 (*assembly flowshop, transportation time*)	F_l (ΣU_j, C_{max}, $\sum E_j^2$, $\sum T_j^2$)	Hybrid *GA*
	Dhouib et al. (2013)	*m* (*time lags*)	ΣU_j	Mathematical programming formulations, *SA*
	Ebrahimi et al. (2014)	*m* (*flexible*)	$\#(C_{max}, \Sigma w_j T_j)$	Non-dominated sorting *GA*, Multi-objective *GA*
	Eren (2010)	*m*	F_l ($\Sigma w_j C_j$, C_{max})	Integer programming model, insertion based heuristics
	Gajpal et al. (2006)	*m*	C_{max}	*ACO*
	Gholami et al. (2009)	*m* (*flexible, machine breakdowns*)	C_{max}	*GA*

(*continued on next page*)

Table 8 (*continued*)

Setup type	References	# of stages (type)	Criterion (comments)	Approach
	Gomez-Gasquet et al. (2012)	*m* (*flexible*)	C_{max}	Agent based *GA*
	Hatami et al. (2010)	*3* (*Assembly flowshop*)	F_l (ΣC_j, T_{max})	Mathematical model, two meta-heuristics based on *SA* and *TS*
	Jabbarizadeh et al. (2009)	*m* (*flexible, machine availability constraint*)	C_{max}	Two metaheuristics based on *GA* and *SA*
	Javadian et al. (2012)	*m* (*flexible, time lags*)	C_{max}	*MIP* model, metaheuristic based on *IA*
	Jolai et al. (2012)	*m* (*flexible, no-wait*)	C_{max}	*SA*, imperialist competitive algorithm, hybridization of both
	Jolai et al. (2014)	*m* (*flexible*, r_j, *transportation time, job rework*)	C_{max}	Enhanced Invasive Weed Optimization algorithm
	Jungwattanakit et al. (2009)	*m* (*flexible, unrelated parallel machines*)	F_l (C_{max}, ΣU_j)	*MIP, SA, TS, GA*
	Karimi et al. (2010)	*m* (*flexible*)	#(C_{max}, Σw_jT_j)	Multi-search *GA*
	Kaweegitbundit (2011)	*m*	C_{max}	*MA, GA*
	Khalili and Naderi (2015)	*m* (*no-wait*)	C_{max}, ΣT_j	*MILP*, imperialist competitive algorithm
	Kia et al. (2010)	*m* (*flexible, dynamic job arrivals*)	ΣF_j, ΣT_j	Dispatching rules and heuristics
	Li and Zhang (2012)	*m*	C_{max}	Different versions of adaptive hybrid *GA*
	Li and Zhang (2012)	*m*	Σw_jT_j	Different versions of adaptive hybrid *GA*
	Li et al. (2010)	*m* (*flexible*)	*Sum of* Σw_jC_j *and deviation of workload*	Two stage heuristic based on modified *GA* and local search
	Li et al. (2011a)	*m* (*flexible, buffers, maintenance*)	*Sum of* Σw_jC_j *and deviation of workload*	Non-linear *MIP* model, two-stage heuristic algorithm
	Lu and Logendran (2013)	*m* (r_j)	F_l (Σw_jC_j, Σw_jT_j)	Mathematical model and *TS*
	Luo et al. (2009a)	*2* (*flexible, zero buffer, maintenance, breakdowns*)	C_{max}	*GA*
	Maboudian and Shafaei (2009)	*2* (*assembly flowshop*)	F_l (C_{max}, T_{max})	Non-linear programming model
	Mansouri et al. (2007, 2009)	*2*	#(C_{max}, *TNS*)	Multi-objective metaheuristics based on *GA* and *SA*
	Mehravaran and Logendran (2012)	*m*	*Min WIP and max customer service level* (r_j)	*MIP* model, *TS*
	Mehravaran and Logendran (2013)	*m* (*permutation and non-permutation*, r_j, *machine availability*)	F_l (Σw_jC_j, Σw_jT_j)	Mathematical model, different search algorithms
	Mirabi (2011)	*m*	C_{max}	*ACO*
	Mirabi (2014)	*m*	C_{max}	A hybrid *GA*
	Mirabi et al. (2008)	*m*	C_{max}	Hybrid *EMA* algorithm
	Mirsanei et al. (2011)	*m* (*flexible*)	C_{max}	*SA* combined with *RKGA* and *IA*
	Moradinasab et al. (2013)	*2* (*flexible, no-wait*)	C_{max}	Adaptive imperialist competitive algorithm, *GA*
	Mousakhani (2013)	*m* (*flexible*)	ΣT_j	Metaheuristic based on *ILS* procedure
	Mousavi et al. (2011)	*m* (*flexible*)	#(C_{max}, ΣT_j)	Bi-objective heuristic
	Mousavi et al. (2012)	*m* (*flexible*)	#(C_{max}, ΣT_j)	Bi-objective *GA* algorithms
	Mozdgir et al. (2013)	*2* (*Assembly flowshop, multiple machines at 2nd stage*)	F_l (C_{max}, ΣC_j)	*MIP*, hybrid neighborhood search heuristic
	Naderi et al. (2009c)	*m* (*flexible, preventive maintenance*)	C_{max}	*VNS* algorithm.
	Naderi et al. (2009d)	*m* (*flexible*)	C_{max}, T_{max}	A hybrid *SA*
	Naderi et al. (2009e)	*m* (*flexible, transportation time*)	Σw_jT_j	*MILP, EMA*
	Nagano et al. (2014)	*m* (*no-wait*)	C_{max}	A hybrid evolutionary cluster search metaheuristic
	Nagano et al. (2015)	*m* (*no-wait*)	ΣC_j	A new constructive heuristic
	Navaei et al. (2014)	*2* (*assembly flowshop*)	Sum of holding and delay costs	Metaheuristics including *SA*
	Nishi et al. (2011)	*m*	Σw_jT_j	Column generation algorithm
	Nishi and Hiranaka (2013)	*m*	Σw_jT_j	Lagrangian relaxation and cut generation, dynamic programming
	Pargar and Zandieh (2012)	*m* (*flexible*)	F_l (C_{max}, ΣT_j)	Mathematical model, A metaheuristic approach called water flow like
	Qian et al. (2011)	*m* (*no-wait*, r_j)	ΣC_j	Hybrid *DE*
	Rabiee et al. (2012)	*2* (*no-wait, probable rework*)	ΣC_j	Adapted imperialist competitive algorithm
	Rabiee et al. (2014)	*2* (*flexible, no-wait, probable rework*)	C_{max}	A hybrid algorithm based on *ICA*
	Rashidi et al. (2010)	*m* (*flexible, blocking processor*)	#(C_{max}, T_{max})	*GA*
	Rossi (2014)	*m* (*flexible, transportation times*)	C_{max}	ACO with reinforced pheromone relationships
	Salhi et al. (2007)	*m* (*flexible*)	C_{max}	Estimation of Distribution Algorithm
	Santos et al. (2014)	m	Σw_jT_j	TS
	Sioud et al. (2013)	*m* (*flexible*)	C_{max}	*GA* with three new crossover operators
	Sioud et al. (2014)	*m* (*flexible*)	C_{max}	*ACO*
	Song et al. (2010)	*2* (*flexible, zero buffer*)	C_{max}	Dispatching rules
	Song et al. (2012)	*2* (*assembly flowshop, limited buffer*)	C_{max}	*GA* hybridized with problem knowledge-based heuristics

(*continued on next page*)

Table 8 (*continued*)

Setup type	References	# of stages (type)	Criterion (comments)	Approach
	Sun (2013)	*2 (setup on the first machine)*	C_{max}	*ACO*
	Tang and Huang (2007)	*m*	C_{max}	*B&B* algorithm, two-stage heuristic algorithm
	Urlings and Ruiz (2007)	*m (flexible, time lags, machine release date)*	C_{max}	*GA* including local search procedures
	Vanchipura et al. (2014)	*m*	C_{max}	Neighborhood search-based heuristics
	Vanchipura and Sridharan (2013a)	*m*	C_{max}	Constructive heuristics
	Vanchipura and Sridharan (2013b)	*m*	*Investigation the effect of setup time on* C_{max}	Two constructive algorithms
	Varmazyar and Salmasi (2012a)	*m*	ΣU_j	Three metaheuristics based on *TS*
	Varmazyar and Salmasi (2012b)	*m*	ΣU_j	Several metaheuristics based on *TS* and *ICA*
	Wang et al. (2014)	*m*	C_{max}	Several versions of ILS
	Wu and Jiang (2007)	*2*	F_l $(\Sigma C_j, C_{max}, E_{max}, T_{max})$	Integer programming model
	Xu and Yin (2011a)	*m*	F_l $(\Sigma w_j C_j, C_{max})$	Integer programming model
	Yaurima et al. (2009)	*m (flexible, unrelated parallel machines, buffer)*	C_{max}	*GA* with a new crossover operator
	Ying et al. (2012b)	*m (no-wait)*	C_{max}	Three metaheuristics based on *GA*, *SA*, Iterated greedy
	Zandieh and Gholami (2009)	*m (flexible, machine breakdowns)*	C_{max}	*IA*
	Zandieh and Karimi (2011)	*m (flexible)*	$\#(C_{max}, \Sigma w_j T_j)$	Multi-population *GA*
	Zandieh et al. (2010)	*m (flexible, time lags, machine release dates)*	C_{max}	*MIP, GA*
	Zhuang et al. (2014)	*m (no-wait)*	C_{max}	Hybrid greedy algorithm
	Ziaee (2013)	*m*	$\Sigma w_j T_j$ *(non-permutation flowshops)*	Local search heuristic

Nagano et al. (2012) provided a new evolutionary clustering search heuristic for the problem Fm/ST_{si}, *no-wait*$/\Sigma C_j$. They showed that their heuristic is effective.

Allahverdi and Aydilek (2014) addressed the problem of Fm/ST_{si}, *no-wait*$/\in(\Sigma C_j/C_{max})$. They proposed an insertion algorithm, two *GA* algorithms, three *SA* algorithms, two cloud theory-based *SA* algorithms, and a *DE* algorithm. The computational analysis showed that one of the *SA* algorithms performs much better than the others under the same computational time. Furthermore, the analysis indicated that the best performing algorithm performs significantly better than the earlier existing best algorithm.

Aldowaisan and Allahverdi (2015) proposed *SA* and *GA* algorithms for the problem of Fm/ST_{si}, *no-wait*$/\Sigma T_j$. They also proposed improved versions of *SA* and *GA* algorithms and showed that the improved versions perform about 95 percent better. Furthermore, they showed that the improved version of *GA* outperforms the improved version of the *SA* by about 3.5 percent.

5.1.3. Flexible (hybrid) flowshop

Lo et al. (2008) presented a *B&B* algorithm for the problem of $FF2/ST_{si}/C_{max}$. They also presented a GA for large size problems. Fattahi et al. (2014) addressed the problem $FF2/ST_{si}/C_{max}$ with assembly operations. Several products of the same kind are ordered to be produced such that the parts are manufactured in the flexible flow shop and products are assembled in the assembly stage. They provided lower bounds and presented a *B&B* algorithm for the problem.

Huang et al. (2009) presented an integer programming model for the problem of $FF2/ST_{si}$, *no-wait*$/\Sigma C_j$. They also presented an *ACO* algorithm and evaluated its performance, and showed that the heuristic performs well.

5.1.4. Assembly flowshop

Allahverdi and Al-Anzi (2008) presented a dominance relation and Allahverdi and Al-Anzi (2009) proposed three heuristics for the $AF2/ST_{si}/\Sigma C_j$ problem. The three heuristics were a hybrid TS and two versions of self-adaptive differential evolution algorithm. They showed that one version of the self-adaptive differential evolution algorithm performs much better than the other version and the hybrid *TS*.

Allahverdi et al. (2015) presented six algorithms for the $AF2/ST_{si}/\Sigma T_j$ problem. The algorithms are different versions of *SA*, *GA*, and insertion algorithms. Moreover, they presented different dominance relations for the problem. The computational experiments indicated that one of their algorithms performs much better than the others. Aydilek et al. (2015b) proposed several dominance relations for the problem of $AF2/ST_{si}/T_{max}$. They also presented a metaheuristic that was shown to perform better than the best existing heuristic in the literature.

Tian et al. (2013) considered the problem of $AF2/ST_{si}/F_l$ $(\Sigma C_j, C_{max})$. They proposed a discrete *PSO* and compared the *PSO* performance with several other heuristics such as *SA* and *TS* and showed that the *PSO* performs well. Azadeh et al. (2012) considered the problem of $AF2/ST_{si}/F_l$ $(\Sigma C_j, C_{max})$ where machines are subject to random breakdowns and setup and processing times are stochastic. They presented an integrated simulation and artificial neural network algorithm for the problem.

5.1.5. Uncertain setup time or processing time

In some real-world situations, setup and/or processing times may be uncertain as a result of random factors such as crew skills, temporary shortage of equipment, tools and setup crews, and unexpected breakdown of fixtures and tools.

Aydilek and Allahverdi (2013) addressed the $F2/ST_{si}/C_{max}$ problem, where processing times are uncertain variables with known lower and upper bounds. They proposed polynomial time heuristics and showed that the average error of one of their proposed heuristics is less than 0.4 percent of the optimal solution. Aydilek et al. (2013) also addressed the same problem of $F2/ST_{si}/C_{max}$ problem but where setup times are uncertain variables within certain intervals. They proposed some polynomial time heuristics which were shown to be very efficient, i.e., the average error of the best heuristic that they proposed was about 0.03 percent of the optimal solution. Aydilek et al. (2015a) generalized the results of Aydilek and Allahverdi (2013) and Aydilek et al. (2013). In other words, they considered the case where both processing times and setup times are uncertain with lower and upper bounds. They presented a dominance relation and proposed an algorithm which was shown to provide solutions close to the optimal solution, i.e., with an absolute error of less than 0.3 percent.

Table 9
Flow shop family setup time scheduling problems ($ST_{si,f}$, $ST_{sd,f}$).

Setup type	References	# of stages (type)	Criterion (Comments)	Approach
$ST_{si,f}$	Schaller (2012)	*m*	ΣT_j	Variable greedy algorithms, *VNS* procedures
	Schaller and Valente (2013)	*m*	$\Sigma(E_j+T_j)$(*non-delay*)	Variable greedy algorithms, *GA*
	Pang (2013)	2 (*no-wait*)	L_{max}	*GA*
	Luo et al. (2012a)	*m* (*flexible*)	C_{max}	*GA*
$ST_{sd,f}$	Behnamian et al. (2010c)	*m* (*flexible*)	$\Sigma(E_j+T_j)$(*due window*)	Hybrid metaheuristic algorithm particle swarm optimization; simulated annealing and variable neighborhood search
	Bouabda et al. (2011a)	*m*	C_{max}	Hybridizing *ILS*
	Bouabda et al. (2011b)	*m*	C_{max}	Cooperative approach including GA and B&B algorithm
	Bozorgirad and Logendran (2013)	*m* (*flexible*)	F_l (Σw_jC_j, Σw_jT_j)	*MILP*, *TS* based algorithms
	Bozorgirad and Logendran (2014)	*m* (*flexible*, r_j)	F_l (Σw_jC_j, Σw_jT_j)	*Lower bound*
	Costa et al. (2014)	*m*	ΣC_j	Hybrid metaheuristic using *GA*
	Hajinejad et al. (2011)	*m*	ΣC_j	*PSO* algorithm
	Hendizadeh et al. (2007)	*m*	$\#(C_{max}, \Sigma C_j)$	Multi-objective *GA*
	Hendizadeh et al. (2008)	*m*	C_{max}	Meta-heuristics based on *TS*
	Ibrahem et al. (2014)	*m*	ΣC_j	*GA*, *PSO*
	Eddaly et al. (2009)	*m*	C_{max}	Evolutionary algorithm incorporating local search
	Fadaei and Zandieh (2013)	*m* (*flexible*)	$\#(C_{max}, \Sigma C_j)$	Different versions of *GA*
	Karimi et al. (2011)	*m* (*flexible*)	C_{max}	*ICA*
	Keshavarz and Salmasi (2013)	*m* (*flexible*)	C_{max}	*MILP*, *MA*
	Keshavarz and Salmasi (2014)	*m*	ΣC_j	*B&B*, a metaheuristic based on GA
	Keshavarz et al. (2015)	*m* (*flexible*)	ΣC_j	*MILP*, a metaheuristic based on *MA*
	Li and Li (2014)	*m*	C_{max}	Hybrid harmony search algorithm
	Lin and Ying (2012)	*m*	$\#(C_{max}, \Sigma C_j)$	Two-level multi-start *SA* heuristic
	Lin and Ying (2012)	*m*	$\#(C_{max}, \Sigma T_j)$ C_{max} *and* ΣT_j	Two-level multi-start *SA* heuristic
	Lin et al. (2009a)	*m*	C_{max}	*SA*
	Lin et al. (2009b)	*m*	C_{max}, T_{max}, ΣC_j, ΣT_j, Σw_jT_j, Σw_jC_j (*non-permutation*)	*SA*, *GA*, *TS*
	Lin et al. (2011c)	*m*	C_{max}	Multi-start *SA*
	Liou and Liu (2010)	2	ΣC_j	Lower bounds, *PSO*
	Liou et al. (2013)	2 (*removal and transportation times*)	C_{max}	Hybrid heuristic of *PSO* and *GA*
	Naderi and Salmasi (2012)	*m*	ΣC_j	*MIP* model, a hybrid heuristic based on *SA* and *GA*
	Salmasi et al. (2009)	*m*	C_{max}	Lower bound
	Salmasi et al. (2010)	*m*	ΣC_j	Branch-and-price, math programming, *TS*, hybrid *ACO*
	Salmasi et al. (2011)	*m*	C_{max}	Math programming, hybrid *ACO*
	Shahvari et al. (2012)	*m* (*flexible*)	C_{max}	Mathematical model, *TS*
	Villadiego et al. (2012)	*m*	ΣC_j	*ILS* heuristic
	Wang et al. (2010a)	2	$\Sigma(E_j+T_j)$ (*due window*)	Two versions of *GA*
	Ying et al. (2010)	*m*	C_{max}, T_{max}, ΣC_j, ΣT_j, Σw_jT_j, Σw_jC_j (*non-permutation*)	*SA*
	Ying et al. (2012b)	*M* (*flexible*, *no-wait*)	C_{max}	Metaheuristics based on *GA*, *SA*, and iterated greedy
	Zandieh et al. (2009)	*m* (*flexible*)	C_{max}	Metaheuristics based on *GA* and *SA*

Gupta et al. (2013) addressed the $F2/ST_{si}/C_{max}$ problem where both setup and processing times are under fuzzy environment and transportation times exist between the two machines. They provided a theorem and presented an algorithm to solve the problem.

Allahverdi (2007) presented some dominance relations for the problem of $F3/ST_{si}/\Sigma C_j$ while Allahverdi (2008) proposed some dominance relations for the $F3/ST_{si}/C_{max}$ problem, where both setup and processing times were considered to be uncertain variables with known lower and upper bounds. Allahverdi (2009) presented some dominance relations for the problem of $F3/ST_{si}/L_{max}$ where again both setup and processing times are uncertain variables with known lower and upper bounds.

5.2. Non-family sequence-dependent setup times (ST_{sd})

As in the previous section, the results for the regular flowshop, no-wait flowshop, flexible flowshop, and assembly flowshop environments are presented in the subsequent subsections, respectively.

5.2.1. Flowshop

Sun (2013) modeled side frame press shop in a truck manufacturing company as a $F2/ST_{sd}/C_{max}$ where there exist setup times only on the first machine and where the first machine has re-entrant work flow. They presented an *ACO* to solve the problem. Wang et al. (2014) presented several *ILS* algorithms for the problem of $Fm/ST_{sd}/C_{max}$.

Lu and Logendran (2013) proposed a mathematical model for the problem of $F2/ST_{sd}/F_l$ (Σw_jC_j, Σw_jT_j). They also proposed a *TS* algorithm for the problem and evaluated the performance of TS by using the mathematical model for small size problems. Wu and Jiang (2007) presented an integer programming model for the problem of $F2/ST_{sd}/F_l$ (ΣC_j, C_{max}, E_{max}, T_{max}).

Mansouri et al. (2007, 2009) addressed the problem of $F2/ST_{sd}/\#(C_{max}, TN)$. They proposed multi-objective metaheuristics based on *GA* and *SA*, and showed that the metaheuristic based on *GA* outperforms that of the one based on *SA*.

The problem of $Fm/ST_{sd}/C_{max}$ has been addressed by many researchers. Gajpal et al. (2006) proposed an *ACO* algorithm and showed that their algorithm outperforms the earlier existing heuristics in the literature. Tang and Huang (2007) proposed a *B&B* algorithm and a two-stage heuristic algorithm. Mirabi et al. (2008) presented a hybrid *EMA* algorithm and showed that their hybrid algorithm performs better than the earlier heuristics while Mirabi (2011) presented an *ACO* algorithm and Mirabi (2014) proposed a hybrid *GA*. Kaweegitbundit (2011) proposed a *MA*, a *GA*, and another heuristic, and showed that the *MA* performs better than the other two. Li and Zhang (2012) presented different versions of adaptive hybrid *GA*, and showed that the performance of different versions of their algorithms depend on the ratio of setup to processing times. Vanchipura and Sridharan (2013a) presented two constructive heuristics. They compared the performances of their heuristics with an earlier existing constructive heuristic and showed that their heuristics, in particular the fictitious job ranking heuristic, performed better than the earlier existing one. Vanchipura, Sridharan, and Babu (2014) also addressed the same problem. They proposed two neighborhood search-based heuristics which were shown to outperform the best heuristic proposed by Vanchipura and Sridharan (2013a). Vanchipura and Sridharan (2013b) considered the same problem with the objective of investigating the effect of setup time on the makespan under the varying proportion of setup time. The heuristics of Vanchipura et al. (2014), Li and Zhang (2012), Kaweegitbundit (2011), Mirabi et al. (2008), and Mirabi (2011, 2014) remain to be compared.

Li and Zhang (2012) presented different versions of adaptive hybrid *GA* for the problem of $Fm/ST_{sd}/\Sigma w_jT_j$. They showed that the performance of different versions of their algorithms depends on the ratio of setup to processing times. Nishi et al. (2011) presented a column generation algorithm, Santos et al. (2014) proposed a *TS* algorithm while Nishi and Hiranaka (2013) presented a Lagrangian relaxation and cut generation method. Nishi and Hiranaka (2013) also developed a dynamic programming to solve sub-problems with cut generation for a set of jobs with constraints. Computational experiments showed that their method is very efficient. Ziaee (2013) addressed the same problem but for non-permutation environments where he showed that the local search based heuristic that he presented outperforms the earlier meta-heuristic methods not only in terms of error but also in terms of computational time. The heuristics of Li and Zhang (2012), Santos et al. (2014), and Ziaee (2013) remain to be compared for permutation environments.

Varmazyar and Salmasi (2012a) presented three metaheuristics based on *TS* for the problem of $Fm/ST_{sd}/\Sigma U_j$. They showed that one of them performs better than the other two. Varmazyar and Salmasi (2012b) presented a *MILP* model and proposed several metaheuristics based on *TS* and *ICA*. They showed that the hybrid heuristic of *TS* and *ICA* performs as the best. Dhouib et al. (2013) presented two mathematical programming formulations and presented an *SA* for the same problem but with time lags which are defined as intervals of time that must exist between every couple of successive operations of the same job.

Jeong and Kim (2014) proposed a *B&B* algorithm and presented heuristics for the problem of $F2//\Sigma T_j$ where ST_{sd} exist on the second machine for jobs in re-entrant environments.

Eren (2010) proposed an integer programming model and developed three insertion based heuristics for the problem of $Fm/ST_{sd}/F_l$ $(\Sigma w_jC_j, C_{max})$. He showed that the heuristics are effective by comparing the performance of the heuristics with the exact solutions. Xu and Yin (2011a) corrected the model of Eren (2010).

Amin-Tahmasbi and Tavakkoli-Moghaddam (2011) presented a mathematical model for the problem of $Fm/ST_{sd}/\#(\Sigma C_j, \Sigma(E_j + T_j))$. They also proposed a multi-objective immune system algorithm and showed that it performs better than two other multi-objective *GA*s.

Mehravaran and Logendran (2012) addressed the problem of $Fm/ST_{sd}, r_j$ with the objective of minimizing work-in-process and maximizing customer service level under both permutation and non-permutation environments. They formulated the problem as a *MIP* and proposed a heuristic algorithm based on TS for solving large size problems. Mehravaran and Logendran (2013) addressed the problem of $Fm/ST_{sd}, r_j/F_l$ $(\Sigma w_jC_j, \Sigma w_jT_j)$ for permutation and non-permutation flowshops with machine availability constraint. They presented a mathematical model and proposed three different search algorithms to solve the problem.

Yu (2014) proposed a metaheuristic heuristic based on *PSO* for the problem of $Fm/ST_{sd}/F_l$ $(\Sigma w_jE_j, \Sigma w_jT_j,$ *machine idle time*$)$ for the multiprocessors flowshop environments.

5.2.2. No-wait flowshop

Zhuang et al. (2014) proposed a hybrid greedy algorithm for the problem of Fm/ST_{sd}, *no-wait*$/C_{max}$. They showed that their proposed algorithm gets best performance against the deterministic heuristics while it outperforms the best non-deterministic one on most instances with the same computation-time.

Rabiee et al. (2012) addressed the problem of $F2/ST_{sd}$, *no-wait*$/\Sigma C_j$ where jobs might have rework. They proposed an adapted *ICA*. They showed that their algorithm performs better than *GA* and population based *SA*. A hybrid algorithm based on *ICA* was proposed by Rabiee et al. (2014) for the problem of $FF2/ST_{sd}$, *no-wait*$/C_{max}$ where jobs might have rework.

Qian et al. (2011) proposed hybrid *DE* algorithm for the problem of Fm/ST_{sd}, *no-wait*, $r_j/\Sigma C_j$. They showed by computational experiments that the algorithm is robust and efficient.

Arabameri and Salmasi (2013) presented proposed a *MILP* model for the Fm/ST_{sd}, *no-wait*$/\Sigma(w_{1j}E_j + w_{2j}T_j)$ problem. They also developed a *TS* algorithm and a *PSO* algorithm. They indicated that the *PSO* algorithm outperforms *TS* algorithm, in particular, for large size problems.

Nagano et al. (2014) addressed the problem of Fm/ST_{sd}, *no-wait*,$/C_{max}$ where they provided a hybrid evolutionary cluster search metaheuristic and showed that it performs well. The problem of Fm/ST_{sd}, *no-wait*$/\Sigma C_j$ was considered by Nagano et al. (2015) where they presented a new constructive heuristic, called QUARTS, which breaks the problem in quartets in order to minimize ΣC_j. On the other hand, Nagano and Araujo (2014) presented two new constructive heuristics for the problem of Fm/ST_{sd}, *no-wait* to minimize C_{max} and total flowtime, respectively. They showed that their heuristics outperform the earlier existing heuristics.

Vanchipura and Sridharan (2014) developed and analyzed of hybrid genetic algorithms for the problem of Fm/ST_{sd}. They developed variations of genetic algorithm by using combinations of initial populations and crossover operators.

5.2.3. Flexible flowshop

Song et al. (2010) evaluated the performance of different dispatching rules for the problem of $FF2/ST_{sd}/C_{max}$ where there exists no buffer space between the two stages. Luo et al. (2009a) addressed the same problem but with maintenance and machine breakdowns. They proposed a *GA* and compared the results of *GA* with that of real life production results which indicated that the *GA* is effective.

Salhi et al. (2007) presented an algorithm, called Estimation of Distribution Algorithm, Abiri et al. (2009) proposed a *TS* algorithm, Alem Tabriz et al. (2009) presented an *SA*, Naderi et al. (2009d) provided a hybrid *SA*, and Naderi et al. (2010b) presented an *ILS* algorithm for the problem of $FFm/ST_{sd}/C_{max}$. They showed that their *TS*, *SA*, and *ILS* algorithms outperform the existing *RKGA*. Mirsanei et al. (2011) presented an *SA* combined with *RKGA* and *IA* for the problem and showed that their *SA* algorithm performs better than the earlier existing *RKGA* and *IA*. Behnamian et al. (2012) addressed the same problem and proposed a hybrid metaheuristic approach integrating several features from the *ACO*, *SA* and *VNS*. Computation results indicated that the hybrid metaheuristic outperforms the earlier existing algorithms. Gomez-Gasquet et al. (2012) presented a multi-agent *GA* for the same problem. Sioud et al. (2013) proposed a GA algorithm, with three new crossover operators, and showed that it performs better than the *ILS* of Naderi et al. (2010b) while Sioud et al. (2014) proposed an *ACO* algorithm. The *TS* algorithm of Abiri et al. (2009), the *SA* algorithm of Alem Tabriz et al. (2009), the *SA* algorithm of Mirsanei et al. (2011), the *GA* algorithm of Gomez-Gasquet et al. (2012), and the *GA* algorithm of Sioud et al. (2013) have not been compared.

Rossi (2014) considered the problem of $FFm/ST_{sd}/C_{max}$ with transportation time. He proposed an *ACO* algorithm with reinforced pheromone relationships and showed that the proposed algorithm performs better.

Naderi et al. (2009c) presented a *VNS* algorithm for the problem of $FFm/ST_{sd}/C_{max}$ with preventive maintenance and showed that the *VNS* heuristic performs well. Jabbarizadeh et al. (2009) addressed the problem of $FFm/ST_{sd}/C_{max}$ with machine availability constraint. They proposed three priority based simple heuristics and two metaheuristics based on *GA* and *SA* to solve the problem.

Gholami et al. (2009) presented a *GA* while Zandieh and Gholami (2009) proposed an *IA* for the problem of $FFm/ST_{sd}/C_{max}$ where machines are subject to random breakdowns. The *GA* of Gholami et al. (2009) and the *IA* of Zandieh and Gholami (2009) have not been compared.

Urlings and Ruiz (2007) proposed a *GA*, including local search procedures, for the problem of $FFm/ST_{sd}/C_{max}$ with time lags and machine release dates. Zandieh et al. (2010) provided a *MIP* model for the same problem. They also presented a *GA* for the problem and compared its performance with some dispatching rules. The *GA* of Zandieh et al. (2010) and the *GA* of Urlings and Ruiz (2007) have not been compared.

Javadian et al. (2012) presented a *MIP* model for the problem of $FFm/ST_{sd}/C_{max}$ with time lags and the possibility of jobs skipping some stages. They also proposed a metaheuristic based on *IA* for the problem.

Yaurima et al. (2009) considered a production environment of a television assembly line for inserting electronic components where the problem can be modeled as $FFm/ST_{sd}/C_{max}$ with availability constraint, unrelated machines, and limited buffers. They proposed a *GA* algorithm and showed that the proposed algorithm improves the current practice.

Moradinasab et al. (2013) presented an adaptive *ICA* and a *GA* for the problem of $FF2/ST_{sd}$, *no-wait*$/C_{max}$. They compared the performance of these algorithms with *ACO* and showed that the algorithms perform better. Jolai et al. (2012) addressed the problem of FFm/ST_{sd}, *no-wait*$/C_{max}$. They proposed three metaheuristic algorithms; *SA*, *ICA*, and a hybridization of both. They showed that the hybridization of the two performed much better than the other two. Since the *FF2* is a special case of *FFm*, the hybridized heuristic of Jolai et al. (2012) and those of Moradinasab et al. (2013) have to be compared. On the other hand, Jolai et al. (2014) proposed an enhanced invasive weed optimization algorithm for the problem of FFm/ST_{sd}, r_j/C_{max} with transportation time and with the possibility of jobs having rework.

Naderi et al. (2009d) presented a hybrid *SA*, including a local search, for the problem of $FFm/ST_{sd}/T_{max}$. They showed that their heuristic performs better than the existing heuristics in the literature.

Mousakhani (2013) presented a *MIP* model for the problem of $FFm/ST_{sd}/\Sigma T_j$, and proposed a metaheuristic algorithm based on *ILS*. They showed that the metaheuristic outperforms *TS* and *VNS* heuristics developed in the literature for other problems. Naderi et al. (2009e) presented an *MILP* model for the problem of $FFm/ST_{sd}/\Sigma w_jT_j$ with transportation times. They also presented an *EMA* and showed that both the *MILP* model and *EMA* are effective. Since the problem addressed by Mousakhani (2013) is a special case of that of Naderi et al. (2009e), their algorithms need to be compared.

Behnamian et al. (2010b) addressed the problem of $FFm/ST_{sd}/\Sigma(E_j + T_j)$. They proposed a hybrid metaheuristic algorithm which comprises three components of *ACO*, *SA*, and *VNS*. A design of experiments approach is employed to calibrate the parameters of the algorithm. They showed that their proposed algorithm is computationally more effective in yielding solutions of better quality than the adapted *RKGA* and *IA* presented previously in the literature. Behnamian and Zandieh (2013) presented a hybrid metaheuristic consisting of *PSO*, *SA*, and *VNS* for the problem of $FFm/ST_{sd}/\Sigma(E_j + T_j)$ where the jobs have position-dependent learning effect. Behnamian and Zandieh (2011) formulated the problem of $FFm/ST_{sd}/\Sigma\ (E_j + T_j^2)$ as a *MIP* and proposed a discrete colonial competitive algorithm. They assumed that the waiting time for each job between two consecutive stages cannot be greater than a given upper bound.

Kia et al. (2010) provided a simulation model addressing the problems of $FFm/ST_{sd}/\Sigma F_j$ and $FFm/ST_{sd}/\Sigma T_j$ for the dynamic job arrivals. They evaluated different dispatching rules and proposed several heuristics. They indicated that one rule performs well for the problem with the performance of ΣF_j while another rule preforms well for the $\Sigma T_{j.}$

Li et al. (2010) presented a non-linear *MIP* model for the problem of FFm/ST_{sd} with the objective of minimizing the sum of Σw_jC_j and absolute deviation of workload of machines. They also proposed a two-stage heuristic algorithm. Li et al. (2011a) addressed the same problem but with limited buffers and maintenance. Li et al. (2011a) proposed a non-linear *MIP* model and proposed a two-stage heuristic algorithm including *GA* and local search. They indicated that the proposed heuristic saves up to 10 percent based on industrial implementation.

Jungwattanakit et al. (2009) addressed the problem of $FFm/ST_{sd}/F_l$ $(C_{max}, \Sigma U_j)$ for the case of unrelated parallel machines. They formulated the problem as a 0–1 *MIP*, presented constructive heuristics, and proposed three metaheuristics, namely, *SA*, *GA*, and *TS*. They showed that *SA* outperforms *GA* and *TS*. Pargar and Zandieh (2012) presented a mathematical model for the problem of $FFm/ST_{sd}/F_l\ (C_{max}, \Sigma T_j)$. They also proposed a metaheuristic called water flow like algorithm and showed that this metaheuristic outperforms the *RKGA*.

Rashidi et al. (2010) presented a *GA* for the problem of $FFm/ST_{sd}/\#(C_{max}, T_{max})$ with the constraint of processor blocking. For the limited buffer environments, Abyaneh and Zandieh (2012) presented a *GA* for the problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma T_j)$. On the other hand, Khalili and Naderi (2015) provided an *MILP* formulations and proposed a bi-objective imperialist competitive algorithm for the problem of FFm/ST_{sd}, *no-wait*/with the objective of minimizing both C_{max} and ΣT_j.

Mousavi et al. (2011, 2012) addressed the problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma T_j)$. Mousavi et al. (2011) proposed a bi-objective heuristic for the problem while Mousavi et al. (2012) developed evolutionary algorithms based on *GA*, with the objective of finding a set of non-dominated solutions (efficient solutions or Pareto front), and showed that their algorithms outperform those of earlier results in the literature. Karimi et al. (2010) presented a multi-search *GA* while Zandieh and Karimi (2011) proposed an adaptive multi-population *GA* for searching Pareto optimal solution for the problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma w_jT_j)$. Ebrahimi et al. (2014) also addressed the same problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma w_jT_j)$ but where due dates are assumed to be random variables following normal distribution. They presented a non-dominated sorting *GA* and a multi-objective *GA* for the problem. The heuristics of Karimi et al. (2010) and Zandieh and Karimi (2011) remain to be compared. Also, the heuristics of Mousavi et al. (2011, 2012) and remain to be compared. Moreover, since the problem of Mousavi et al. (2012) is a special case (with job equal weights) of the problem addressed by Zandieh and Karimi (2011), their heuristics need to be compared. Asefi et al. (2014) proposed a metaheuristic for the problem of FFm/ST_{sd}, *no-wait*$/\#(C_{max}, \Sigma w_jT_j)$.

Behnamian et al. (2009b, 2011b) considered the problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma(E_j{+}T_j))$. Behnamian et al. (2009b) proposed a multi-phase covering Pareto-optimal front method by using a hybrid metaheuristic including *RKGA* while Behnamian et al. (2011b) proposed a hybrid metaheuristic consisting of *ACO*, *SA*, and *VNS*.

Behnamian and Ghomi (2011) considered the problem of $FFm/ST_{sd}/\#(C_{max}$, *total resource allocation cost*) where there are unrelated parallel machines. They developed a multi-objective hybrid metaheuristic with the objective of obtaining Pareto-optimal solutions. The hybrid heuristic combines *GA* and *VNS*. Behnamian et al. (2014) proposed a hybrid heuristic, which consists of *PSO*, *TS*, and *VNS*, while Behnamian (2014a) presented parallel algorithms for the problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma(E_j+T_j))$. On the other hand, Behnamian and Ghomi (2014) proposed a *PSO* algorithm for the problem of $FFm/ST_{sd}/\#(C_{max}, \Sigma(E_j+T_j))$ where processing and setup times are considered to be fuzzy along with fuzzy due dates.

Behnamian (2014b) proposed a colonial competitive algorithm for the problem of $FFm/ST_{sd}/\#(F_l\ (C_{max}, \Sigma E_j, \Sigma T_j$, *# of worker employed*) for the case of simultaneous effects of learning and deterioration.

5.2.4. Assembly flowshop

Song et al. (2012) considered the problem of $AF2/ST_{sd}/C_{max}$ with limited intermediate buffers. They proposed a *GA* hybridized with problem knowledge-based heuristics and showed that it is efficient by computational experiments. On the other hand, Navaei et al. (2014) proposed hybrid metaheuristics, including *SA*, for the problem of $AF2/ST_{sd}/C_{max}$ where there exist more than one machine at the second stage and where the objective is to minimize the sum of holding and delay costs.

Mozdgir et al. (2013) addressed the problem of $AF2/ST_{sd}/F_l\ (C_{max}, \Sigma C_j)$ such that there are a number of non-identical machine at the second stage. They presented a *MIP* model and proposed a hybrid neighborhood search heuristic. They indicated that the proposed heuristic performs well when compared to the optimal solutions obtained by the *MIP* model.

Dalfar et al. (2012) considered the problem of $AF2/ST_{sd}/F_l\ (\Sigma U_j, C_{max}, \sum E_j^2, \sum T_j^2)$ with transportation times. They presented a hybrid *GA* and evaluated its performance with the optimal solution for small size problems.

Maboudian and Shafaei (2009) addressed the problem of $AF2/ST_{sd}/F_l\ (C_{max}, T_{max})$. They presented a lower bound and proposed a non-linear programming model for the problem.

Hatami et al. (2010) addressed the $AF3/ST_{sd}/F_l\ (\Sigma C_j, T_{max})$ problem with transfer times. They presented a mathematical model and proposed two meta-heuristics based on *SA* and *TS* for the problem.

5.3. Family sequence-independent setup times ($ST_{si,f}$)

Pang (2013) presented a *GA* for the problem of $F2/ST_{si,f}$, *no-wait*$/L_{max}$, and showed that it is effective. Schaller (2012) presented variable greedy algorithms and *VNS* procedures for the problem of $Fm/ST_{si,f}/\Sigma T_j$. He showed that variable greedy algorithms are effective for small size problems while *VNS* procedures are effective for large size problems.

Schaller and Valente (2013) addressed the problem of $Fm/ST_{si,f}/\Sigma(E_j + T_j)$ for the case of non-delay schedules. They presented variable greedy algorithms along with a *GA*. They showed that the greedy algorithms are efficient for small size problems while the *GA* performs well for medium and large size problems.

Luo et al. (2012a) addressed the problem of $FFm/ST_{si,f}/C_{max}$ and presented a *GA*. They showed that the *GA* is efficient.

5.4. Family sequence-dependent setup times ($ST_{sd,f}$)

Liou et al. (2013) addressed the problem of $F2/ST_{sd,f}/C_{max}$ with transportation times and sequence-dependent family removal times. They presented some lower bounds and proposed a hybrid heuristic consisting of *PSO* and *GA*. Three lower bounds were developed by Liou and Liu (2010) for the problem of $F2/ST_{sd,f}/\Sigma C_j$. They also presented a *PSO* algorithm and evaluated its performance with the developed lower bounds. Wang et al. (2010a) proposed two versions of *GA*, a niche *GA* and a standard *GA*, for the problem of $F2/ST_{sd,f}/\Sigma(E_j + T_j)$ where each job has a due window.

The problem of $Fm/ST_{sd,f}/C_{max}$ has been addressed by many researchers. Hendizadeh et al. (2008) proposed meta-heuristic algorithms based on *TS* by applying the concept of elitism and the acceptance of worse move to improve the intensification and diversification of moves. Computational analysis showed that the earlier existing *MA* was superior. Lin et al. (2009a) presented an *SA* algorithm for the problem and showed that their *SA* algorithm outperforms the *TS* of Hendizadeh et al. (2008). An evolutionary algorithm incorporating an *ILS* algorithm was proposed by Eddaly et al. (2009). Salmasi et al. (2009) presented a lower bound while Salmasi et al. (2011) proposed a mathematical programming model and a hybrid *ACO* algorithm for the problem. Salmasi et al. (2009) showed that their lower bound performs better than the existing lower bounds while Salmasi et al. (2011) indicated that the hybrid algorithm outperforms the earlier existing *MA* in the literature. Bouabda et al. (2011a) proposed a hybridizing *ILS* algorithm, which uses *B&B* algorithm inside an *ILS*, whereas Bouabda et al. (2011b) presented a cooperative approach, including *GA* and *B&B* algorithm, for the problem. Lin et al. (2011c) also addressed the problem where they presented a multi-start *SA* and compared its performance with an earlier established lower bound. On the other hand, Li and Li (2014) presented a hybrid harmony search algorithm for the problem. The heuristics of Salmasi et al. (2011), Eddaly et al. (2009), Lin et al. (2009a), and Lin et al. (2011c) have not been compared with each other.

The problem of $Fm/ST_{sd,f}/\Sigma C_j$ was addressed by Salmasi et al. (2010) for the first time. They proposed a mathematical programming model and a branch-and-price algorithm. In addition, they presented a *TS* algorithm along with a hybrid *ACO* algorithm. The computational analysis indicated that the hybrid approach performs better than *TS*. Hajinejad et al. (2011) proposed a *PSO* algorithm and showed that their algorithm outperforms the hybrid heuristic of Salmasi et al. (2010). Villadiego et al. (2012) presented an *ILS* heuristic and showed that their *ILS* heuristic outperforms the *PSO* of Hajinejad et al. (2011). On the other hand, Costa et al. (2014) proposed a hybrid metaheuristic using *GA* and biased random sampling. Naderi and Salmasi (2012) presented two versions of *MIP* model, and proposed a hybrid heuristic based on *GA* and *SA*. Naderi and Salmasi (2012) showed that their hybrid heuristic outperforms the hybrid heuristic of Salmasi et al. (2010). Keshavarz and Salmasi (2014) proposed several improvements to enhance the branch-and-price algorithm of Salmasi et al. (2010) and also proposed a metaheuristic algorithm based on *GA*. Keshavarz and Salmasi (2014) showed that their metaheuristic outperform those of Hajinejad et al. (2011) and Naderi and Salmasi (2012). Ibrahem et al. (2014) proposed a *GA* and a *PSO* algorithm for the same problem. The heuristics of Ibrahem et al. (2014) and that of Keshavarz and Salmasi (2014) remains to be compared. Keshavarz et al. (2015) provided an *MILP* formulation and a metaheuristic based on *MA* for the problem of $FFm/ST_{sd,f}/\Sigma C_j$.

Ying et al. (2010) considered the problem of $Fm/ST_{sd,f}$ with respect to six different performance measures of C_{max}, T_{max}, ΣC_j, ΣT_j, Σw_jT_j, and Σw_jC_j. They proposed an *SA* algorithm showing that there are significant improvements by using non-permutation schedules over permutation schedules by using the given performance measures. Lin et al. (2009b) also considered the problem of $Fm/ST_{sd,f}$ with the same six performance measures. They proposed *SA*, *TS*, and *GA* and showed that the improvement made by non-permutation schedules over permutation schedules for the due date based performance criteria were significantly better than those of the completion time based criteria. Lin et al. (2009b) indicated that their proposed *SA* and *GA* outperform the *TS* of Hendizadeh et al. (2008) for the C_{max} performance measure.

Hendizadeh et al. (2007) proposed a multi-objective *GA* for the problem of $Fm/ST_{sd,f}/\#(C_{max}, \Sigma C_j)$. They showed that their proposed algorithm deviates only about 1 percent of lower bounds. Lin and Ying (2012) addressed the same problem and proposed a two-level multi-start *SA* heuristic and showed that the heuristic is efficient in terms of both solution quality and computational time when compared to the multi-objective *GA* of Hendizadeh et al. (2007). Moreover, Lin and Ying (2012) also addressed the problem of $Fm/ST_{sd,f}/\#(C_{max}, \Sigma T_j)$ and used the same heuristic of two-level multi-start *SA* to solve the problem.

Zandieh et al. (2009) proposed two metaheuristics based on *GA* and *SA* for the problem of $FFm/ST_{sd,f}/C_{max}$ and showed that the heuristics outperform the earlier existing one. Karimi et al. (2011) proposed an *ICA* algorithm for the problem and showed that their algorithm outperforms *RKGA*. Shahvari et al. (2012) proposed a mathematical model and presented another *TS* algorithm for the problem. They showed that their *TS* algorithm outperforms the earlier existing *TS* algorithms. Keshavarz and Salmasi (2013) developed an *MILP* model for the problem and presented an *MA*. They also proposed a lower bounding technique and showed that their *MA* outperforms the *TS* algorithm of Shahvari et al. (2012). The metaheuristics of Zandieh et al. (2009), *ICA* of Karimi et al. (2011), and the *MA* of Keshavarz and Salmasi (2013) has not been compared.

Ying et al. (2012b) addressed the problem of $FFm/ST_{sd,f}$, *no-wait*/C_{max}. They proposed three metaheuristics based on *GA*, *SA*, and iterated greedy. They showed that the metaheuristic based on *SA* performed better than the other two.

Behnamian et al. (2010c) addressed the problem of $FFm/ST_{sd,f}/\Sigma(E_j + T_j)$ where each job has a due window. They proposed a hybrid metaheuristic algorithm combining elements from *PSO*, *SA*, and *VNS*.

Bozorgirad and Logendran (2013) addressed the problem of $FFm/ST_{sd,f}/F_l$ $(\Sigma w_jC_j, \Sigma w_jT_j)$. They presented a *MILP* model and proposed four *TS* algorithms. They showed that one of the *TS* algorithms performs well. On the other hand, Bozorgirad and Logendran (2014) presented a lower bound for the problem of $FFm/ST_{sd,f}$, r_j/F_l $(\Sigma w_jC_j, \Sigma w_jT_j)$. Fadaei and Zandieh (2013) proposed several different versions of *GA*, *GA* with multiple objectives, for the problem of $FFm/ST_{sd,f}/\#(C_{max}, \Sigma T_j)$.

6. Job shop and open shop

A job shop environment consists of *m* different machines and each job has a given machine route in which some machines can be missing and some can repeat. Similar to flowshops, there may exist more than one machine in at least one stage, which is called a flexible job shop. On the other hand, in an open shop, each job should be processed once on each of the *m* machines passing them in any order. No subsections are provided in this section. Job shop results are presented followed by the results for open shops. For each shop environment, however, the results are summarized in the same sequence as in the other shop environments. Hence the results are summarized in the sequence of ST_{si}, ST_{sd}, $ST_{si,f}$, and $ST_{sd,f}$. Moreover, the single objective function results are discussed followed by multiple objective results for each setup time environment. A summary of the scheduling literature on job shop and open shop problems is presented in Table 10.

Many researchers addressed the problem of $J/ST_{sd}/C_{max}$. Zhou et al. (2006) presented an *MIP* model, proposed a biological *IA* and showed that their algorithm outperforms those of existing ones in the literature. Moghaddas and Houshmand (2008) presented a mathematical model, proposed three lower bounds, and developed a heuristic algorithm based on some priority rules. Roshanaei et al. (2010a) presented an *MILP* model and proposed an *EMA* algorithm and showed that the *EMA* algorithm outperforms the *IA* of Zhou et al. (2006). Naderi et al. (2009a) proposed a hybrid GA and showed that their hybrid *GA* outperforms the biological *IA* of Zhou et al. (2006). Roshanaei et al. (2009) proposed a *VNS* algorithm and showed that the *VNS* algorithm outperforms the *IA* algorithm of Zhou et al. (2006) and the hybrid *GA* of Naderi et al. (2009a). González et al. (2008) presented a *GA* hybridized with local search while González et al. (2009) proposed a combined *GA* and *TS* and showed that their algorithms outperform a heuristic presented in 2001. González et al. (2012b) proposed an *MA* that combines *GA* and a local search using *TS* and showed that the *MA* outperforms some earlier results. Zhang et al. (2009) developed a scheduling model based on timed Petri nets where they introduced control arcs. They also presented a *B&B* algorithm. Naderi et al. (2010a) proposed a metaheuristic based on *SA*, including an effective local search and showed that it outperforms the hybrid *GA* of Naderi et al. (2009a). Shen (2014) proposed a *TS* algorithm and showed that the *TS* performs better than the hybrid *SA* of Naderi et al. (2010a). Vela et al. (2010) presented a local search method and a *GA*, and a hybrid of *GA* and local search and compared their performances with some bench mark problems. Peng (2013) proposed three heuristics (binary constraint, variable-based, and task-based) for the same problem and showed that the binary constraint heuristic performs better than the other two heuristics. The *EMA* of Roshanaei et al. (2010a), the *VNS* of Roshanaei et al. (2009), the *MA* of González et al. (2012b), the *TS* of Shen (2014), the hybrid *GA* of Vela et al. (2010) remain to be compared.

Naderi et al. (2009b) addressed the $J/ST_{sd}/C_{max}$ problem with preventive maintenance. They proposed four metaheuristics based on *GA* and *SA*, and compared those metaheuristics with each other and with two other existing heuristics of *GA* and immune system. They showed that one of their proposed metaheuristics based on *GA* performs as the best. Sun (2009) considered the problem $J/ST_{sd}/C_{max}$ with re-entrant operations. He proposed a *GA* and two heuristic procedures, which are modified versions of existing methods. He showed that the *GA* performs better than the two heuristics.

Balas et al. (2008) addressed the problem of J/ST_{sd}, *prec*, r_j/C_{max} and proposed a heuristic based on shifting bottleneck procedure. They showed by computational experiments, mainly from the semiconductor industry, that their heuristic substantially outperforms the state of the art.

González et al. (2010) proposed a disjunctive graph representation and presented a neighborhood structure while González et al. (2013) proposed a *TS* algorithm for the problem of $J/ST_{sd}/L_{max}$. They defined a new local search neighborhood structure which was incorporated into the *TS* and was shown to be effective.

Eguchi et al. (2013) considered the problem of $J/ST_{sd}/\Sigma T_j$ for the case of dynamic job arrivals. They proposed a mixture of *GA* and switching priority rules. González et al. (2012a) addressed the problem of $J/ST_{sd}/\Sigma w_jT_j$ where they proposed a hybrid metaheuristic combining *GA* and *TS*. They tested their heuristic across conventional benchmarks and showed that it compares favorably to the state of the art methods. Driessel and Mönch (2012) considered the same problem but with re-entrant process flow and transportation. They proposed decomposing the problem into single machine scheduling problems and presented *VNS* based sub-problems solution procedures.

Manikas and Chang (2009a) proposed a scatter search metaheuristic for the problem of J/ST_{sd} with the objective of minimizing a linear combination of earliness, tardiness, C_{max}, and job ranking. They showed that their metaheuristic outperforms *GA*, *SA*, and *TS*. Manikas and Chang (2009b) proposed a *GA* for the same problem but where jobs may have re-entrant flow.

Vinod and Sridharan (2008, 2009) addressed the problem of J/ST_{sd} for the case of dynamic job arrivals. The performance measures they considered were ΣT_j, ΣF_j, *TST*, and *TNS*. By conducting extensive simulation experiments, they showed that setup-oriented rules perform better than ordinary rules. Sharma and Jain (2015) assesses the performance of different dispatching rules for the problem of J/ST_{sd} for stochastic dynamic shop environments considering the performance measures of C_{max}, ΣF_j, ΣT_j, T_{max}, *U*, and *TST*.

Fakhrzad et al. (2013) considered the problem of $J/ST_{sd}/\#(C_{max}, \Sigma(E_j + T_j))$ in a time window. They proposed a multi-objective hybrid *GA* and a multi-objective evolutionary algorithm. They

Table 10
Job shop and open shop scheduling problems (ST_{si}, ST_{sd}, SC_{sd}, $ST_{sd,f}$).

Shop environment (J/O)	Setup type	References	Criterion (comments)	Approach
J	ST_{sd}	Bagheri and Zandieh (2011)	F_l (C_{max}, ΣT_j)	*VNS* algorithm
		Balas et al. (2008)	C_{max} (*Prec*, r_j)	Heuristic based on "shifting bottleneck procedure"
		Defersha and Chen (2010)	C_{max} (*flexible, time lags, machine release dates*)	Mathematical model, *GA*
		Driessel and Mönch (2012)	Σw_jT_j (*re-entrant process flow*)	*VNS* based sub-problem solution procedures
		Eguchi et al. (2013)	ΣT_j (*dynamic job arrivals*)	*GA* and switching priority rules
		Fakhrzad et al. (2013)	$\#(C_{max}, \Sigma(E_j+T_j))$	Multi-objective hybrid *GA*, multi-objective evolutionary algorithm
		González et al. (2008)	C_{max}	*GA* hybridized with local search
		González et al. (2009)	C_{max}	Combined *GA* and *TS*
		González et al. (2010)	L_{max}	TS combined with a neighborhood structure
		González et al. (2012a)	Σw_jT_j	Hybrid metaheuristic combining *GA* and *TS*
		González et al. (2012b)	C_{max}	*MA*
		González et al. (2013)	L_{max}	*TS*
		Imanipour (2006)	C_{max} (*flexible*)	Non-linear *MIP* model, *TS*
		Manikas and Chang (2009a)	*A linear comb. of earliness, tardiness,* C_{max}, *job ranking*	Scatter Search metaheuristic
		Manikas and Chang (2009b)	*A linear comb. of earliness, tardiness,* C_{max}, *job ranking*(*re- entrant flow*)	Scatter Search metaheuristic
		Moghaddas and Houshmand (2008)	C_{max}	Mathematical model, lower bounds, a heuristic
		Naderi et al. (2009a)	C_{max}	Hybrid *GA*
		Naderi et al. (2010a)	C_{max}	Metaheuristic based on *SA*
		Naderi et al. (2009b)	C_{max} (*preventive maintenance*)	Metaheuristics based on *SA* and *GA*
		Nourali et al. (2012)	C_{max} (*flexible*)	*MIP* model
		Nourali and Imanipour (2014)	C_{max} (*flexible*)	*PSO*
		Özgüven et al. (2012)	C_{max} (*primary*) *and workload* (*secondary*) (*flexible*)	*MIP* models
		Roshanaei et al. (2009)	C_{max}	*VNS*
		Roshanaei et al. (2010a)	C_{max}	*MILP* model, *EMA*
		Rossi and Dini (2007)	C_{max} (*flexible, transportation time*)	*ACO*
		Peng (2013)	C_{max}	Binary constraint heuristic, variable-based and task-based heuristic
		Sadrzadeh (2013)	C_{max}, ΣT_j (*flexible*)	Artificial Immune System, *PSO*
		Saidi-Mehrabad and Fattahi (2007)	C_{max} (*flexible*)	*MILP*, *TS*
		Sharma and Jain (2015)	C_{max}, ΣF_j, ΣT_j,, T_{max}, *U*, *TST* (stochastic dynamic shop environments)	Dispatching *rules*
		Shen (2014)	C_{max}	*TS*
		Sun (2009)	C_{max} (*re-entrant operations*)	*GA*, heuristics
		Tavakkoli-Moghaddam et al. (2011a,b)	$\#(\Sigma w_jC_j, \Sigma(w_{1j}T_j+w_{2j}E_j))$	Integer programming, *PSO* combined with genetic operators
		Vela et al. (2010)	C_{max}	*GA*, local search method
		Vinod and Sridharan (2008, 2009)	*flowtime, tardiness, setup time, # of setups* (*dynamic*)	Different dispatching rules
		Zhang et al. (2009)	C_{max}	Timed Petri nets, *B&B* algorithm
		Zhang and Liu (2012)	C_{max} (*flexible, prec*)	Hybrid *ACO* algorithm
		Zhou et al. (2006)	C_{max}	*MIP* model, a biological *IA*
	SC_{sd}	Huq et al. (2009)	*Number of early jobs* (*flexible*)	Different dispatching rules
	$ST_{sd,f}$	Halat and Bashirzadeh (2015)	C_{max} (*transportation time*)	MILP, GA
		Prot and Bellenguez-Morineau (2012)	L_{max} (r_j, *multi-mode with assembly*)	Lower bound, *TS*
		Zhang and Gu (2009)	C_{max}	Timed Petri nets
O	ST_{si}	Low and Yeh (2009)	ΣT_j (*removal times*)	0–1 integer programming model, hybrid *GA*-based heuristic
	ST_{sd}	Naderi et al. (2011)	ΣC_j	*EMA* metaheuristic
		Noori-Darvish et al. (2012)	$\#(\Sigma w_jT_j, \Sigma w_jC_j)$ (*fuzzy processing times and due dates*)	Bi-objective *MIP* model, multi-objective *PSO*
		Roshanaei et al. (2010b)	C_{max}	*SA* based metaheuristics, *GA*

showed that the multi-objective hybrid *GA* performs better than the multi-objective evolutionary algorithm. Tavakkoli-Moghaddam et al. (2011a, 2011b) addressed the problem of $J/ST_{sd}/\#(\Sigma w_jC_j, \Sigma(w_{1j}T_j + w_{2j}E_j))$ where they presented an integer programming model. They also proposed a *PSO* combined with genetic operators and showed that it performs better than a multi-objective *GA*.

Zhang and Gu (2009) proposed a method to model the problem of $J/ST_{sd,f}/C_{max}$ as timed Petri nets. Comparison with some previous work shows that their model is more compact and effective in finding the best solution. Halat and Bashirzadeh (2015) proposed a *MILP* formulation and a *GA* for the problem of $J/ST_{sd,f}/C_{max}$ with transportation time.

Prot and Bellenguez-Morineau (2012) presented a *TS* for the problem of $J/ST_{sd,f}$, r_j/L_{max} with multi-mode and assembly. They also presented a lower bound and evaluated the performance of their *TS* by using the lower bound.

Imanipour (2006) modeled the problem of $FJ/ST_{sd}/C_{max}$ as a nonlinear *MIP* model and proposed a *TS* algorithm. Another *MIP* model was presented by Nourali et al. (2012) while Nourali and Imanipour (2014) proposed a *PSO* algorithm. Saidi-Mehrabad and Fattahi (2007) proposed a *TS* algorithm and showed that the *TS* algorithm performs well by comparing its performance with optimal solutions obtained by *B&B* algorithm. Sadrzadeh (2013) proposed an artificial immune system algorithm and *PSO* algorithm. He showed that the artificial immune system algorithm performs better than *PSO* and several other algorithms including *GA* and *VNS*. The immune system algorithm of Sadrzadeh (2013) and the TS algorithms of Imanipour (2006) and Saidi-Mehrabad and Fattahi (2007) remain to be compared.

Zhang and Liu (2012) proposed a hybrid *ACO* for the problem of $FJ/ST_{sd}, prec/C_{max}$ with unrelated machines. They showed that the *ACO* outperforms *GA* significantly. Rossi and Dini (2007) considered the problem of $FJ/ST_{sd}/C_{max}$ with transportation time. They proposed an *ACO* algorithm and compared with another *ACO* and other algorithms from the literature. They showed that their proposed *ACO* algorithm performs better. Defersha and Chen (2010) presented a mathematical model for the problem of $FJ/ST_{sd}/C_{max}$ with time lags and machine release dates. They also presented a *GA*.

Sadrzadeh (2013) addressed the problem of $FJ/ST_{sd}/\Sigma T_j$ and proposed an artificial immune system algorithm and *PSO* algorithm and showed that the artificial immune system algorithm performs better than *PSO* and several other algorithms including *GA* and *VNS*. Huq et al. (2009) evaluated the performance of different dispatching rules such as *SPT* and *LPT* with respect to minimizing the number of early jobs while simultaneously approximating Just-in-Time inventory levels for flexible job shops in the presence of non-zero setup costs.

Yu and Ram (2006) and Yu, Ram, and Jiang (2007) addressed the parameter modeling and optimization issues in the application of a bio-inspired model for the problem of FJ/ST_{sd} for dynamic job arrivals. Bagheri and Zandieh (2011) presented a *VNS* algorithm for the problem of $FJ/ST_{sd}/F_l\ (C_{max}, \Sigma T_j)$. They computationally showed that the algorithm is efficient.

Özgüven et al. (2012) addressed the problem of FJ/ST_{sd} with the primary objective of minimizing C_{max} and balancing the machine workload as a secondary objective. They presented two mixed integer goal programming models; one for the case of separable setup times and the other for the case of non-separable setup times. Guimaraes and Fernandes (2006) presented a *GA* for the problem of FJ/ST_{sd} with multiple criteria which include C_{max}, *TST*, and workloads of machines.

Low and Yeh (2009) considered the problem of $O/ST_{si}/\Sigma T_j$ where there exist sequence-dependent removal times. They proposed a 0–1 integer programming model and presented a hybrid *GA* based heuristic. They showed that the hybrid *GA* based heuristic performs better than *GA*, *SA*, and *TS*. Roshanaei et al. (2010b) addressed the problem of $O/ST_{sd}/C_{max}$. They proposed a multi-neighborhood search *SA*, a hybrid *SA*, and *GA* for the problem, and showed that the multi-neighborhood search *SA* performs better than the others. Naderi et al. (2011) presented an *MIP* model for the problem of $O/ST_{sd}/\Sigma C_j$. They also proposed an *EMA* metaheuristic for the problem and showed that the metaheuristic is effective. Noori-Darvish et al. (2012) presented a bi-objective *MIP* model for the problem of $O/ST_{sd}/\#(\Sigma w_jT_j, \Sigma w_jC_j)$. They also proposed a multi-objective *PSO*.

7. Conclusions

Global economy forces firms to be competitive in order to survive. This implies that firms have to increase productivity, eliminate waste and non-value added activities, and improve the effective utilization of resources. Explicit consideration and treatment of setup times/costs while making scheduling decisions help in succeeding all the three objectives in addition to meeting deadlines. As a result, researchers have addressed different scheduling problems with setup times/costs since mid-1960s. The first comprehensive review, Allahverdi et al. (1999), on scheduling problems with setup times/costs covered about 200 papers while the second comprehensive review paper, Allahverdi et al. (2008), covered about 300 papers. This is the third comprehensive review of the problem which surveys about 500 papers. The current survey paper, along with those of Allahverdi et al. (1999, 2008), is an up to date survey of scheduling problems involving static, dynamic, deterministic, and stochastic problems for different shop environments (single machine, parallel machines, flowshop, job shop, and open shop) with setup times/costs since the first research on the topic appeared in the mid-1960s. The time span of Allahverdi et al. (1999) is much longer than those of Allahverdi et al. (2008) and the current paper while the time span of Allahverdi (2008) is longer than that of the current paper. This shows that the interest in scheduling problems with setup times/costs is growing. However, the research on scheduling problems with setup times/costs is still less than 10 percent of the available research on scheduling problems while the majority of scheduling environments involve setup operations. Hence, more research on scheduling problems with explicit consideration of setup times/costs is needed.

Some researchers independently have addressed the same problem. These problems have been identified throughout this paper and their results have not been compared. These results are summarized in Table 11 where the first column denotes the addressed problem; the second column denotes the references addressing the same problem while the third column shows which method have been utilized. For example, the problem $FFm/ST_{sd}/C_{max}$ has been independently studied by Abiri et al. (2009), Alem Tabriz et al. (2009), Mirsanei et al. (2011), Gomez-Gasquet et al. (2012), and Sioud et al. (2013) by using *TS*, *SA*, *SA*, *GA*, and *GA* respectively. Therefore, these results remain to be compared. It should be noted that, in general, even if methods of two researchers are the same, they may be completely different as they may use different operators and different parameter values. For example, the *GA* of Gomez-Gasquet et al. (2012) is not the same as the *GA* of Sioud et al. (2013). It should be also noted that some problems are special cases of some other problems. For example, the problem $1/ST_{sd}/\Sigma T_j$ is a special case of the problem $1/ST_{sd}/\Sigma w_jT_j$. Therefore, if a heuristic has been developed for the problem of $1/ST_{sd}/\Sigma w_jT_j$, and in a later date, another heuristic has been presented for the problem of $1/ST_{sd}/\Sigma T_j$, then both heuristics need to be compared. Table 11 does not provide those problems, however, throughout the paper, these problems have been identified and the need for comparing these heuristics has been specified.

Single machine, parallel-machine, flowshop, job shop and open shop problems have been addressed in about 150, 90, 160, 45, 5 papers, respectively. Single machine and parallel machine refer to the single stage scheduling environments, and hence, more than half of the papers addressed the single stage scheduling problems. Therefore, more research is needed for multiple stage scheduling environments. Regarding to family and non-family setup problems, even though for single machine and flowshop scheduling environments, the ratio of family setup to non-family setup is about 41 percent and 32 percent, respectively, while the ratio is about 11 percent and 8 percent for the parallel and job shop environments, respectively. This clearly indicates the need for considering family setup time for the parallel and job shop environments. In general, the vast majority of papers addressed the sequence-dependent setup times/costs compared to sequence-independent setup times/costs. This is good since sequence-independent problem is a special case of sequence-independent problem. However, for the single machine environment with family setup time case, about 75 percent of the papers addressed the sequence-independent problem. This indicates the need for addressing the sequence-dependent scheduling problems in single machine environments with family setup times.

The widely used methods are *GA*, *SA*, *ACO*, and *PSO*. *GA* has been used in about 100 papers while each of *SA* and TS have been utilized in about 40 papers. *ACO*, *VNS*, *PSO*, have been utilized in about 25, 20, and 20, respectively. All other heuristics have been used in about 10 or less papers. Among the exact solutions methods, *MIP* is utilized in about 50 papers while about 30 papers utilized *B&B*.

The performance measure C_{max} has been addressed in about 40 percent of the papers, which is the most commonly used measure. This is expected since the performance measure of C_{max} is directly related to the utilization of resources. This performance measure is followed by total tardiness performance measure. About 25 percent

Table 11
Methods needed to be compared.

Problem	Reference	Approach
$1/ST_{sd}/T_{max}$	Luo et al. (2006a)	*B&B*
	Luo and Chu (2007)	*B&B*
$1/ST_{sd}/\Sigma T_j$	Luo and Chu (2006)	*B&B*
	Luo et al. (2006a)	*B&B*
	Bigras et al. (2008)	*B&B*
$1/ST_{sd}/\Sigma T_j$	Armentano and De Araujo (2006)	Memory-based GRASP
	Arroyo et al. (2009)	ILS
	Akrout et al. (2012)	DE
	Sioud et al. (2012b)	Hybrid GA
$1/ST_{sd}/\Sigma w_jT_j$	Deng and Gu (2014)	An iterated greedy algorithm
	Guo and Tang (2011)	Scatter based metaheuristic
	Luo et al. (2012b)	Iterated filter-and-fan algorithm
	Subramanian et al. (2014)	ILS
	Xu et al. (2014c)	Hybrid evolutionary algorithms
$1/ST_{sd}/TST$	Ye et al. (2006)	ACO
	Ozgur and Bai (2010)	Hierarchical heuristic
$1/ST_{sd}/\Sigma(E_j+T_j)$	Chen et al. (2007)	GA
	Hepdogan et al. (2009)	Metaheuristic
	Chen and Chen (2011)	GA
$1/ST_{sd,f}/L_{max}$	Jin et al. (2009a)	TS
	Jin et al. (2009b)	SA
	Jin et al. (2010)	TS
$P/ST_{sd}/C_{max}$	Behnamian et al. (2009a)	A hybrid algorithm consisting of ACO, SA, and VNS
	Hu and Yao (2011a)	GA
	Hu and Yao (2011b)	GA
$P/ST_{sd}, r_j/C_{max}$	Jairo et al. (2009)	Heuristic
	Montoya-Torres et al. (2010)	Heuristic
$P/ST_{sd}, r_j/L_{max}$	Lee et al. (2010)	Restricted SA
	Ying and Cheng (2010)	Iterated greedy heuristic
$R/ST_{sd}/C_{max}$	Lin and Ying (2014)	Artificial bee colony algorithm
	Arnaout et al. (2014)	*ACO*
	Avalos-Rosales et al. (2015)	Metaheuristic
	Niu et al. (2011)	Adaptive clonal selection algorithm
$R/ST_{sd}/\Sigma T_j$	Ying and Lin (2012)	Artificial bee colony algorithm
	Lee et al. (2013)	TS
$Fm/ST_{sd}/C_{max}$	Vanchipura et al. (2014)	Neighborhood search-based heuristics
	Li and Zhang (2012)	Adaptive hybrid GA
	Kaweegitbundit (2011)	MA
	Mirabi et al. (2008)	Hybrid EMA
	Mirabi (2011)	ACO
	Mirabi (2014)	A hybrid GA
$FF2/ST_{sd}$, *no-wait*$/C_{max}$	Jolai et al. (2012)	Metaheuristic based on SA and ICA
	Moradinasab et al. (2013)	Adaptive ICA, GA
$Fm/ST_{sd,f}/C_{max}$	Salmasi et al. (2011)	Hybrid ACO
	Eddaly et al. (2009)	Evolutionary algorithm incorporating an ILS
	Lin et al. (2009a)	SA
	Lin et al. (2011c)	Multi-start SA
$Fm/ST_{sd,f}/\Sigma C_j$	Ibrahem et al. (2014)	GA, PSO
	Keshavarz and Salmasi (2014)	Metaheuristic based on GA
$FFm/ST_{sd}/C_{max}$	Abiri et al. (2009)	TS
	Alem Tabriz et al. (2009)	SA
	Mirsanei et al. (2011)	SA
	Gomez-Gasquet et al. (2012)	GA
	Sioud et al. (2013)	GA
$FFm/ST_{sd}/C_{max}$ (*machine breakdowns*)	Gholami et al. (2009)	GA
	Zandieh and Gholami (2009)	IA
$FFm/ST_{sd}/C_{max}$ (*time lags*)	Zandieh et al. (2010)	GA
	Urlings and Ruiz (2007)	GA
$FFm/ST_{sd,f}/C_{max}$	Zandieh et al. (2009)	Metaheuristic
	Karimi et al. (2011)	ICA
	Keshavarz and Salmasi (2013)	MA
$FFm/ST_{sd}/\#(C_{max}, \Sigma T_j)$	Mousavi et al. (2011)	Bi-objective heuristic
	Mousavi et al. (2012)	Evolutionary algorithms
$FFm/ST_{sd}/\#(C_{max}, \Sigma w_jT_j)$	Karimi et al. (2010)	GA
	Zandieh and Karimi (2011)	GA
$J/ST_{sd}/C_{max}$	Roshanaei et al. (2010a)	EMA
	Roshanaei et al. (2009)	VNS
	González et al. (2012b)	MA
	Shen (2014)	TS
	Vela et al. (2010)	Hybrid GA
$FJ/ST_{sd}/C_{max}$	Sadrzadeh (2013)	Immune system algorithm
	Imanipour (2006)	TS
	Saidi-Mehrabad and Fattahi (2007)	TS

of the papers have used this performance measure. This is also expected since on time delivery of products is very important in the current competitive work environment. The total completion time performance measure, which is directly related to work-in process, has been addressed in about 20 percent of the papers. All other performance measures have been used in less than 7 percent of the papers. Again in the current competitive work environment, firms strive to save in every possible ways, and minimizing work-in process is a major cost saving. It has been observed that the total completion time performance measure has been addressed by a relatively less number of papers for the single machine, parallel machine, and job shop environments. It has been also observed that total tardiness performance measure has been only utilized in a few papers for the job shop environments. Therefore, there is a need to consider these performance measures in those scheduling environments.

The multiple criteria scheduling problems constitute less than 10 percent of the papers while in real life many scheduling problems require multiple criteria. Therefore, there exists a need to address more scheduling problems with multiple criteria.

In some real-world situations, setup times may be uncertain as a result of random factors such as crew skills, tools and setup crews, and unexpected breakdown of fixtures and tools. However, only a few papers addressed setup times as uncertain variables, and thus, there is need to address more scheduling problems with uncertain setup times.

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