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Editorial

The significance of reducing setup times/setup costs

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Abstract

Scheduling with setup times or setup costs plays a crucial role in todays modern manufacturing and service environments where reliable products/services are to be delivered on time. Scheduling activities profoundly depend on the times/costs required to prepare the facility for performing the activities. However, the vast majority of existing scheduling literature ignores this fact. We define and emphasize the importance, applications, and benefits of explicitly considering setup times/costs in scheduling research. Moreover, a review of the latest research on scheduling problems with setup times/costs is provided.

Keywords: Scheduling; Setup time; Setup cost

1. Introduction

The decision to provide multiple products/services on common resources results in the need for changeover and setup activities. Setup activities due to changeovers represent costly disruptions to production/service processes. Therefore, setup reduction is an important feature of the continuous improvement program of any manufacturing/service organization. It is even more critical if an organization expects to respond to changes like shortened lead times, smaller lot sizes, and higher quality standards. Every scheduler should understand the principles of setup reduction and be able to recognize the potential improvements.

We provide a formal definition of setup times/costs, discuss the importance and benefits of reducing setup times/costs, give some important application areas where setup times/costs have been explicitly taken into account, and present the latest relevant scheduling research.

2. Definition of setup time/cost

Setup time, in general, can be defined as the time required to prepare the necessary resource (e.g., machines, people) to perform a task (e.g., job, operation). Setup cost is the cost to set up any resource used prior to the execution of a task. Setup activities may include, for example, (1) obtaining tools, positioning work in process material, returning tools, cleaning up, setting the required jigs and fixtures,

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adjusting tools, and inspecting material in a *manufacturing system*, (2) setting up a suitable environment to perform tasks in a *service organization*, (3) transferring programs and their dependent files as well as their run times in a *computer system*, and (4) holding the data signals steady before the clock event so that the signals sampled by the clock are reliable in *synchronous circuits* such as the flip-flop.

In some situations where setup time and setup cost are proportional, which typically occur when the resource idle time is the only concern, it is sufficient to consider either setup time or setup cost. However, in other situations, where the cost of changeovers between certain tasks is relatively high even though the setup time is relatively low, the setup cost is of more significance (this may occur in environments requiring high-skilled labor).

There are two types of setup time or setup cost: sequence-independent and sequence-dependent. If setup time/cost depends solely on the task to be processed, regardless of its preceding task, it is called sequence-independent. On the other hand, in the sequence-dependent type, setup time/cost depends on both the task and its preceding task. In some environments, there may be different families or batches of tasks which involve (minor) setup times/costs among the tasks within a family and (major) setup times/costs among the task families. The family setup time/cost can be also sequence-independent or sequence-dependent.

3. Importance and benefits of reducing setup times/costs

In todays scheduling problems in both manufacturing and service environments it is of significance to efficiently utilize various resources. Treating setup times/costs separately from processing times/costs allows operations to be performed simultaneously and hence improves resource utilization. This is, in particular, important in modern production management systems such as just-in-time (JIT), optimized production technology (OPT), group technology (GT), cellular manufacturing (CM), and time-based competition.

The benefits of reducing setup times/costs include: reduced expenses, increased production speed, increased output, reduced lead times, faster changeovers, increased competitiveness, increased profitability and satisfaction, enabling lean manufacturing, smoother flows, broader range of lot sizes, lower total cost curve, fewer stockouts, lower inventory, lower minimum order sizes, higher margins on orders above minimum, faster deliveries, and increased customer satisfaction.

The importance and benefits of incorporating setup times/costs in scheduling research has been investigated by many researchers since mid 1960s. For example, in a survey of industrial managers, Panwalkar et al. (1973) observe that about 75% of the managers require separate treatment of setup times. Krajewski et al. (1987) point out that simultaneous reduction of setup times and lot sizes is the most effective means to reduce inventory levels and to improve customer service. Flynn (1987) demonstrates that scheduling with setup times/costs increases output capacity in cellular manufacturing environments, while Wortman (1992) underlines the problem importance in effectively managing the manufacturing capacity. Kogan and Levner

Table 1
Percentage of setup time reduction

Industry	Equipment	Setup time reduction (%)
Assembly	Adhesive applicator	97
	Air cleaner assembly	100
Brake mfg	Briquette press	82
	Drill machine	86
	Segment drill	90
Cosmetics	Capper machine	65
Electronics	PCB inserion-ICs	56
	PCB insertion-axial	19
	PCB insertion-radial	91
	Assembly	86
Foundry	Molding machine	38
Grid computing	IBM and turboworx solution	90
Metal cutting	Casting drill	85
	CNC MILLING	100
	FADAL HMC	85
Metal fab.	40 Ton press	92
	750 Ton hyd press	68
	800 Ton press	97
	Aluminum extruder	97
	Brake press	89
	Draw press	33
	Edge trim press	83
	Pilot change-muffler press	96
Packaging	Flex packaging line	94
Paper	Sheeting	80
Pharmaceutical	Centrifuge	82
Plastics	250 Ton injection molder	86
	Injection molder	96
	Injection molder	98
Printing	Kidder 6-color web press	73
	Press make ready	54
Wood	Router	86

(1998) discover that treating setup times as separate can significantly reduce makesapan in an automated manufacturing line with robots. Liu and Chang (2000) state that the setup time/cost is a significant factor in production scheduling; it may easily consume more than 20% of available resource capacity. Trovinger and Bohn (2005) report that as much as 50% of effective capacity can be lost due to setup activities in a printed circuit board assembly. Applying a setup time reduction approach, they estimate a reduction of setup times by more than 80%, and direct benefits of $1.8 million per year. Table 1 illustrates the percentages of setup time reductions across various industries (Strategos, 2006).

4. Applications areas

In many practical environments, it is necessary to consider setup times as separate from processing times. These applications can be found in various production, service, and information processing systems. For example, in a *computer system* application, a job requires a setup time to load a different compiler if the current compiler is not suitable. In a *printing industry*, a setup time is required to prepare the machine (e.g., cleaning) which depends on the color of the current and immediately following jobs. In a textile industry, setup time for weaving and dying operations depends on the jobs sequence. In a *container/bottle industry*, setup time relies on the sizes and shapes of the container/bottle, while in a plastic industry different types and colors of products require setup times. Similar situations arise in *chemical, pharmaceutical, food processing, metal processing, paper industries*, and many other industries/areas for which a sample is provided in Table 2.

5. Current scheduling research with setup times/costs

This feature issue contains 21 papers. The first is by Allahverdi, Ng, Cheng, and Kovalyov which provides a comprehensive survey on scheduling problems with separate setup times or costs. It covers more than 300 papers since the earlier survey paper of Allahverdi et al. (1999), which included about 190 papers from the mid 1960s. The recent surge of interest in the scheduling with setup times/costs demonstrates the importance of the problem to both researchers and practitioners. This new survey classifies scheduling problems based on (i) batching and non-batching, (ii) sequence-independent and sequence-dependent setup times/costs,

Table 2
Application areas for scheduling with setup times/costs

Industry/area	Sample reference
Aerospace	Li (1997)
Assembly	Strategos (2006)
Auto	Yi and Wang (2003)
Brake manufacturing	Strategos (2006)
Carpet	Yuzukirmizi (2006)
Chemical	Riane (1998), Fortemps et al. (1996)
Chip	Benini et al. (2006)
Circuit board	Pearn et al. (2004)
Cluster computing	Lin et al. (2005)
Computer systems	Allahverdi et al. (1999)
Communication	Tse and Lun (2003)
Construction	Yang et al. (this feature issue)
Cosmetics	Strategos (2006)
Database	Allahverdi and Al-Anzi (2006)
Disaster relief	Pillalamarri et al. (2005)
Die-casting	Chen and Wu (2006)
Drugs and cosmetics	Lamothe et al. (2006)
Electronics	Monkman (this feature issue)
Finance and mutual fund	Khorana et al. (2005)
Food processing	Bitran and Gilbert (1990)
Foundry	Strategos (2006)
Glass	Chevalier et al. (1996), Paul (1979)
Grid computing	IBM (2005a)
Health care	IBM (2005b)
Information processing	Allahverdi et al. (1999)
Label sticker manufacturing	Lin and Liao (2003)
Lighting	Sherali et al.(this feature issue)
Manufacturing	Soroush (2006), Choi and Choi (2002)
Metal fabrication, rolling and cutting	Strategos (2006)
Metallurgical	Narasimhan and Mangiameli (1987)
Packaging	Strategos (2006)
Paint	Ruiz and Stutzle (this feature issue)
Paper	Sherali et al. (1990)
Pharmaceutical	Rosenzweig et al. (2006)
Pipe and valve	Flowers and Karalli (2006)
Plastic	Radhakrishnan and Ventura (2000)
Printing	Strategos (2006)
Robot and automated guided vehicle (AGV)	Hall et al. (2000)
Routing and navigation	Nauss (this feature issue)
Satellite imagining	Lin et al. (2005a)
Scientific computing	Havill and Mao (this feature issue)
Semiconductor	Gupta and Sivakumar (2005)
Service	Allahverdi et al. (1999)
Software	Narasimhan et al. (2001)
Textile	Aghezzaf et al. (1995), Sherali et al. (1990)
Tile	Andrés et al. (2005)
Web service	Cardoso et al. (2004)
Wood	Riane (1998)

and (iii) shop environments, including single-machine, parallel machines, flow shop, no-wait flow shop, flexible flow shop, job shop, open shop, and others.

In the following subsections, we classify the remaining papers, of this feature issue as those which are concerned with single machine, parallel machine, flow shop scheduling, and others.

5.1. Single machine scheduling

Yang and Chand examine learning and forgetting effects on the problem of scheduling families of jobs on a single machine to minimize the total completion time of all jobs, where a setup time occurs whenever the machine switches the processing of a job from one family to another. Three models are presented and compared to investigate the impact of learning and forgetting. These models include cases with no forgetting, total forgetting, and partial forgetting assuming position dependent job processing times. They provide a branch-and-bound algorithm and a heuristic procedure.

Koulamas and Kyparisis address a single-machine scheduling problem in which setup times are proportionate to the length of jobs already scheduled. They consider make span, total completion time, total absolute differences in completion times as well as a combination of the last two as their objective functions. They show that, using any of these objective functions, the problem can be solved by a sorting procedure. Furthermore, they demonstrate that the results can be extended to scheduling problems in "learning" environments where setup times are no longer linear functions of the already elapsed processing time due to learning effects.

Schaller and Gupta study a single machine scheduling problem to minimize total earliness and tardiness with family setup times. They present a branch-and-bound algorithm with and without group technology assumption. A heuristic is also proposed for the case with the group technology assumption. They empirically show that scheduling without using the group technology assumption can considerably reduce total earliness and tardiness.

Mosheiov and Oron consider a single-machine batch scheduling problem in order to minimize total flow time, where job processing times are identical and setup times are equal for all batches with bounded sizes. They solve the problem under two scenarios: batch sizes have either a common upper bound or a common lower bound.

Kacem and Chu explore a single machine scheduling problem of minimizing the weighted sum of the completion times where there exists a planned setup period during which the machine is not available. They present two heuristics and discuss their worst-case performance ratios.

5.2. Parallel machine scheduling

Leung, Ng, and Cheng study the problem of assigning jobs into batches and scheduling the batches on parallel identical machines with the objective of minimizing the sum of completion times. Each job processing time is assumed to be a step function of its waiting time; i.e., the time between the start of the processing of the batch to which the job belongs and the start of the processing of the job. They show that the problem is strongly NP hard, even for a single machine and a fixed deteriorating step. They present an algorithm for the special case of the identical basic processing times and also propose an approximation algorithm for the general case which is shown to have a performance guarantee of two.

Monkman, Morrice, and Bard provide a three-step heuristic for a production scheduling problem at a high volume assemble-to-order electronics manufacturer. They consider sequence-dependent setups of multiple product families on parallel identical machines with the objective of minimizing total setup costs. The steps of the heuristic involve assignment, sequencing, and time scheduling, with an optimization approach developed for each step. Their empirical results show a reduction in setup costs up to 20%.

Aubry, Rossi, Espinouse, and Jacomino study the problem of minimizing setup costs involved in the configuration of parallel machines under the constraint that a load-balanced production plan can be made to satisfy all demands. They show that the problem is NP-hard and formulate it as an integer programming model. Under certain conditions the problem is solved using a transportation model and the performance of such a solution is analyzed.

Havill and Mao address the problem of scheduling perfectly malleable parallel jobs with arbitrary arrival times on multiple processors, where malleable parallel jobs can distribute their workload among any number of available processors in a parallel computer in order to decrease their execution time. They consider both the linear speedup and the setup times of jobs. For the objective of minimizing makespan, they present an online algorithm which is simpler than previous offline algorithms for scheduling malleable jobs that require more than a constant number of passes through the job list.

5.3. Flow shop scheduling

Ruiz and Stutzle present a heuristic procedure for multiple machines flow shop scheduling problem with either makespan or weighted tardiness objectives, where setup times are sequence-dependent. The procedure involves two phases: a construction/destruction phase based on an iterated greedy concept and an acceptance test phase based on the simulated annealing concept. Their computational results show that the proposed approach performs better than the existing approaches for both makespan and weighted tardiness objectives.

Yang, Kuo, and Chern examine a two-machine multi-family scheduling problem with reentrant production flows to minimize makespan. The jobs in the same family are identical and are processed in succession. A machine requires a setup time when a job comes from a different family. The problem is shown to be NP-hard, a branch-and-bound algorithm is proposed, and computational experiments are provided.

Liu studies the single-job lot streaming problem in a two-stage hybrid flowshop involving multiple identical machines at the first stage and one machine at the second stage with the objective of minimizing makespan. Before processing each sublot on a machine, a setup time is required. Given the number of sublots, a rotation method is used to allocate and sequence the sublots on the machines, and then linear programming is used to optimize the sublot sizes. An efficient solution method is also presented for determining the optimal number of sublots with equal sublot sizes. For the general case, heuristics are proposed and their worst-case performances are analyzed.

Yokoyama considers a hybrid flowshop scheduling problem with setup time and assembly operations. Initially, jobs are processed in a flow-shop consisting of multiple machines, and then are assembled into finished products on a single assembly machine. The objective is to minimize the mean completion time for all finished products. A pseudo-dynamic programming method and a branch-and-bound method are proposed. Computational results show that good schedules can be obtained efficiently.

5.4. Other scheduling problems

Kats, Lei, Levner study a single-robot cyclic scheduling problem with setup times and processing time window constraints, where the objective is to minimize the cycle time. They show that the problem is equivalent to the parametric critical path problem, and propose a strongly polynomial time algorithm. The algorithm, which is an extension of the well known Bellman-Ford algorithm, uses a new labeling procedure to identify the parametric critical path on the network.

Andres, Miralles, Pastor extend the classical simple assembly line balancing problem by including sequence-dependent setup times within work stations. The objective is to minimize the number of work stations while observing the precedence relationships and maintaining an upper bound on the cycle time. A mathematical programming model is presented, and heuristic procedures are proposed and evaluated.

Mosheiov and Oron address an m-machine open shop batch scheduling problem with identical jobs and sequence-independent setup times and batch availability. The objective is to minimize either makespan or mean flow time. They show that the problem with minimizing makespan is solvable in constant time. Since the complexity of the problem with minimizing the mean flow time is unknown, they propose an algorithm which extends the solution of the single machine case.

Sherali, Van Goubergen, and Van Landeghem discuss a problem emerging in the setup management of manufacturing systems by considering an environment with multiple machines that form a line requiring set-up operations to be performed by multiple workers. They present a mathematical model and an algorithm for scheduling jobs in order to minimize the set-up time taking into account some relevant secondary objectives such as balancing the workload amongst the workers, concentrating slack toward the end of the set-up process, and minimizing the movement costs of the workers performing different set-up tasks.

Mika, Waligora, and Weglarz study a multi-mode resource-constrained project scheduling problem with non-preemptable activities, renewable resources, and schedule-dependent setup times. A schedule-dependent setup time is defined as a setup time which depends on the assignment of resources to activities over time. The objective is to minimize the project duration. They propose a tabu search procedure which is compared with a multi-start iterative improvement method.

Berk, Toy, and Hazir address the single item dynamic demand capacitated lot-sizing problem for a warm/cold process with both zero and non-zero setup times as well as lost sales. Lost sales for a given period have no affect on the demand of the next period. To keep the process warm for the next period, production should exceed a given threshold. The objective is to determine the minimum quantity production in order to keep the process warm. They present a dynamic programming approach.

Nauss investigates the problem of sequencing tow/barges through a river lock when queues are formed under extreme conditions which arises from the Upper Mississippi River navigation system. Setup times incur when "exchange situation" or "turnback situation" takes place which depend on the direction of the travel (upstream or downstream) and whether two tow/barges are processed from either the same side or the opposite side of the lock. The author presents a linear/nonlinear integer programming model with the objective of minimizing a linear combination of makespan, total setup time, and weighted (unweighted) total completion time.

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