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Review

A comprehensive review of flowshop group scheduling literature

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A B S T R A C T

Due to its practical relevance, the flowshop group scheduling problem has received much attention in the academic and practice-oriented literature. As machines are grouped to cells and parts to part families, this problem is also known as cellular manufacturing scheduling. Group scheduling is characterized by sequencing tasks on two levels: on the one hand, a sequence of part families has to be determined considering major family setup times while, on the other hand, a job sequence has to be found within each part family. Despite an increasing number of publications, no comprehensive review on group scheduling and its solution methods has been conducted so far. This paper intends to close this gap by reviewing the development of research and characterizing the considered problem. All publications are categorized regarding the number of machines, type of setup times as well as the solution approach. Furthermore, group scheduling in flexible flowshop environments as well as a related scheduling task in multiple cells, known as cell scheduling problem, is considered. Finally, open problems and promising fields for future research in the area of flowshop group scheduling are identified.

Contents

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1. Introduction

The development and utilization of group technology (GT) and cellular manufacturing (CM) continue to have a great impact on the implementation of efficient batch manufacturing systems that face today's challenges [1]. While group technology is defined as "a manufacturing philosophy that identifies and exploits the underlying sameness of parts and manufacturing processes" [2], the implementation of GT in a manufacturing environment is referred to as CM [3], which has been GT's major application [4]. In cellular manufacturing systems (CMS), resources are divided into smaller organizational units called manufacturing cells, each of which produces certain sets of products referred to as part families. Besides the minimization of setup costs, the main advantage of CM is a simplification of material flows. Through the responsibility of a team for a limited set of parts, production control can be handled within each cell autonomously. As a result, an improved operator expertise is achieved, which leads to a more reliable production with improved quality and lower rework costs. Furthermore, implementation of GT and CMS can achieve shorter throughput times, lower stocks, decreases material handling and production costs [4,5]. Thus, CM is especially advantageous for systems with complex material flows and a high level of automation like flexible manufacturing systems.

Three major planning tasks become necessary in CMS, which, apart from few exceptions [6,7], are usually solved independently: First, the cell formation problem which implies the grouping of machines to manufacturing cells as well as the formation of part families and their assignment to cells. Part families are usually formed according to the required operations, machines and tooling. Second, a layout problem has to be solved by positioning manufacturing cells in the shop floor and machines within each cell. Finally, all jobs and operations have to be scheduled. The cell formation and cell layout problem have received much attention in the literature [3,8,9]. However, research on developing efficient and effective scheduling systems that are crucial to fully gain the advantages of CM has appeared only recently. While traditional production systems often constitute job shop environments, CMS flowline manufacturing cells are quite common in practice, as the objective of GT is to create simple material flows [10]. Either the assignment of more than just one part family to a cell or the splitting of part families to subfamilies that require a similar tooling (also "tooling families") still results in a complex sequencing task referred to as group scheduling: on the one hand, a sequence of jobs or parts within each part family has to be determined while, on the other hand, a family sequence must be identified taking family setup times into account. While these two decisions are described separately, there is an interaction and interdependence between them, thus, increasing the complexity of formulating and solving the resulting group scheduling problem.

Group scheduling has proven to be relevant in various areas beyond classical CMS even though the literature mostly uses terminology and developments of CMSs. This is shown by its diverse practical applications, such as automotive paint and body shops [11], furniture production [12], label sticker manufacturing [13], semiconductor industry [14], blades for airplane engines [15], punching machines for metal parts [16], manufacturing of centrifugal pumps [17], printed circuit board (PCB) [18], TFT-LCD production [19] or electronics manufacturing in general [20] but also bridge construction problems [21] and wine bottling [22]. After Hitomi and Ham [23] first stated the flowshop group scheduling problem in 1976, the development of algorithms to solve this problem has attracted numerous researchers and practitioners. Vaithianathan and McRoberts [24] discussed the idea of decomposing scheduling problems with part families into two levels and compared the complexity of the arising problem to traditional flowshop and job shop problems. Following this, through simulation studies in dynamic environments with stochastic job arrivals, it was shown that exhaustive scheduling rules, i.e. all parts of a family are processed subsequently, outperform non-exhaustive rules in terms of both, mean flow time and mean tardiness [25]. After that, especially algorithms that were originally developed to solve traditional flowshop problems have been modified and applied to solve static group scheduling problems, where all jobs, part families and parameters are known in advance. While in the beginning sequence-independent setup times have been considered only, Flynn [26] highlighted the need to include sequence-dependent setups, which has been the predominantly considered type of setup time recently.

Despite strong computational resources nowadays, only small to medium size problems can be solved by exact methods [20]. Hence, various constructive heuristics and metaheuristic approaches have been developed for the real-world flowshop group scheduling problems. Nevertheless, even though various reviews on scheduling had been conducted within the last decades, until today no comprehensive overview of group scheduling approaches has been given. Among these were studies covering scheduling problems with setup considerations and, hence, partly containing group scheduling literature. Allahverdi et al. [27,28] and Allahverdi [29] presented thorough reviews on scheduling problems with setup considerations in various shop environments, whereas other surveys confined themselves to flowshop scheduling in general [30] or scheduling problems with sequence-dependent setup times [31,32]. Potts and Kavalyov [33] concentrated on scheduling with batching, of which group scheduling can be seen as a special case of serial batching. However, due to the exponentially growing number of publications on scheduling, there is still a recurring need for up-to-date surveys focusing on either specific solutions methods or particular problem classes [28]. Therefore, in this paper, we provide a comprehensive review of the development of the approaches and algorithms developed to solve the flowshop group scheduling problems excluding flowshop group scheduling of identical jobs (also known as batch scheduling of identical jobs) and the class of lot-streaming problems. To the best of our knowledge, this is the first approach to systematically give an overview of flowshop group scheduling literature and to provide guidance for a classification of existing solution algorithms.

The rest of this paper is structured as follows: First, a detailed definition of the flowshop group scheduling problem, its extensions and complexity as well as commonly used solution representations are presented in Section 2. Afterwards, in Section 3 a distinction to related problems and an analysis of flowshop group scheduling approaches is conducted, which emphasizes the development of literature and its solution approaches over the last years and identifies the relevant journals for publications on group scheduling. The specific publications are classified and presented into four categories following the historical development of group