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Review

Multi-objective permutation flow shop scheduling problem: Literature review, classification and current trends

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ABSTRACT

The flow shop scheduling problem is finding a sequence given *n* jobs with same order at *m* machines according to certain performance measure(s). The job can be processed on at most one machine; meanwhile one machine can process at most one job. The most common objective for this problem is makespan. However, many real-world scheduling problems are multi-objective by nature. Over the years there have been several approaches used to deal with the multi-objective flow shop scheduling problems (MOFSP). Hence, in this study, we provide a brief literature review of the contributions to MOFSP and identify areas of opportunity for future research.

Contents

1. Introduction

Flow shop scheduling is an attractive research area in manufacturing. It is not only a theoretical field of study but also an interesting field of application in industry and in many other real-world situations. The flow shop production practice examples from the literature are chronologically given as follows. Hodgson et al. [47] studied a model with stochastic production time and deterministic customer-specified due dates. They applied this model to single-facility and flow shop production environment. The real problem was of Naval Aviation Depot (NADEP). Another example is the study of Liu and Chang [65]. In that study, they focused on an approach for production scheduling of flexible flow shop with significant sequence-dependent setup effects like time and cost. They applied the algorithm to IC (Integrated Circuit) probing machines and tested the solution with 16 cases. The third application is of Aghezzaf and Van Landeghem [1]. In this paper, a photographic film production was considered. In the real-life example, there were two production stages which the first stage was process type and the second one was batch production. The next example is the study of Boukef et al. [13]. They developed a genetic algorithm code to solve flow shop scheduling problems. Later, they specifically applied their solution technique to pharmaceutical and agro-food industries in order to show the efficiency of the code. Chandra et al. [19] discussed a study which is done for a production planning and scheduling problem of a medium-sized, bulk-drugs manufacturer producing customized

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products in India in the fifth example. The last study is of Xu and Zhou [121]. In this study, an application of flow shop scheduling problem in a famous automotive manufacturing company was discussed. These examples show that there is a wide variety of applications in industry in terms of flow shop scheduling.

Flow shop scheduling problem that focuses on a single objective has attracted many researchers over time. Wide range of solution methods including exact methods (Ignall and Schrage [49], McMahon and Burton [67], Tseng et al. [115]), heuristics (Nawaz et al. [79], Palmer [84], Smith and Dudek [106], Kalczynski and Kamburowski [54]) and metaheuristics (Osman and Potts [83], Ogbu and Smith [81], Ruiz et al. [100], Onwubolu and Davendra [82], Qian et al.[88], Vallada and Ruiz [117]) have been proposed in the literature.

Since most real life scheduling problems naturally involve multiple objectives, the Multi-Objective Flow shop Scheduling Problem (MOFSP) has been studied in many researches in recent years. Two or more objectives, such as makespan, flowtime, tardiness, earliness, idle time and their different combinations are considered in these studies. Over the years, several optimization and near optimization techniques have been developed for solving the MOFSPs.

Approaches for solving multi-objective problems (MOP) are generally divided into three classes according to the role of the decision maker in the solution process [9,35,111]:

(1) A priori approach: The decision maker gives all the necessary information at the beginning of the decision making process. This can be done in two ways. In the first way, a weighted combination of the objectives is minimized [3,25,77]. In the second way, the objectives are hierarchically optimized, i.e. the optimum value of primary objective is firstly found. Then, the secondary objective is optimized with the primary objective's optimum value [43,93,113].
(2) A posteriori approach: Firstly, a set of efficient (or non-dominated or Pareto-optimal) solutions is developed. Then, the decision maker chooses one solution from this set [7,9,27,71,85,90,91,92,102,104].
(3) Interactive approach: The decision maker introduces the preferences during the solution process. At the each step of the procedure, the decision maker expresses his most preferred solution interactively. The process determines a satisfying compromise between the considered objectives for the decision maker [4].

The motivation of this study is the fewness of review papers about the MOFSPs in the literature. Additionally, the most of the review studies deal with single objective problems or they do not focus on the most recent heuristics and metaheuristics for MOFSP. Framinan et al. [32] reviewed and classified heuristics for permutation flow shop scheduling with makespan. Ruiz and Maroto [99] provided an updated and comprehensive review of flow shop heuristics and metaheuristics. Another recent review was written by Reza Hejazi and Saghafian [98]. They focused on the flow shop scheduling problems with makespan objective. The literature in which the flow shop scheduling problem modeled as a traveling salesman problem (TSP) was reviewed by Bagchi et al. [10]. Gupta and Stafford [44] summarized the developments in flow shop scheduling over the last fifty years. Minella et al. [70] reviewed the literature for MOFSP and carried out a computational evaluation of 23 different algorithms, including those specific for permutation flow shop problems or general multi-objective proposals. Vallada and Ruiz [118] gave a review of metaheuristics for permutation flow shop scheduling studies to minimize total tardiness and makespan. Finally, Sun et al. [108] provided a general survey of the literature on the MOFSP. In the present paper, the main objective is to cover the wide scope of the MOFSP including recent publications and to provide a taxonomy classification for the MOFSP, and we identify areas of opportunity for future research.

The rest of the paper is organized as follows. In Section 2, the basic terminology of the flow shop scheduling problem and notation are presented, and the general structure of the MOFSP is described. In Section 3, an up-to-date research review for the MOFSP is given. Finally, conclusions and directions for future research are discussed in Section 4.

2. Definitions and notation

The flow shop scheduling problem consists of scheduling n jobs with the same order and given processing times on m machines. The problem has the following assumptions [11,99]: (i) Each job i can only be processed on one machine at any time, (ii) Each machine j can process only one job i at any time, (iii) No preemption is allowed, i.e. the processing of a job i on a machine j cannot be interrupted, (iv) All jobs are independent and are available for processing at time zero, (v) The set-up times of the jobs on machines are sequence independent and are included in processing times, (vi) The machines are continuously available.

Generally, a multi-objective optimization problem with k objectives can be described as follows:

$$\text{Minimize}\, f_1(x), f_2(x), \ldots, f_k(x) \tag{1}$$

subject to $x \in X$,
where $f_1(x), f_2(x), \ldots, f_k(x)$ are k objectives to be minimized, x is the decision vector, and X is the set of feasible solutions.

The following concepts are important for multi-objective optimization:

Pareto dominance: A decision vector a ($a \in X$) is said to (Pareto) dominate a decision vector b ($b \in X$) (denoted $a \prec b$) if and only if the following two conditions hold:

$$\forall i \in \{1, 2, \ldots, k\} : f_i(a) \le f_i(b) \tag{2}$$

$$\exists j \in \{1, 2, \ldots, k\} : f_j(a) < f_j(b) \tag{3}$$

Pareto-optimal solution: A solution $x \in X$ is Pareto-optimal solution if there is no $x' \in X$ that dominates x. An image of a Pareto-optimal solution is called nondominated.

Pareto-optimal set: The set containing all Pareto-optimal solutions is called the Pareto-optimal set.

Pareto front: The set of all objective function values corresponding to the solutions in the Pareto-optimal set is a Pareto front.

We describe the n-job, m-machine flow shop scheduling problem using the notations given below. π stands for a feasible sequence of jobs in this notation:

p_{ij}	Processing time of job i on machine j
p_i	Total processing time of job i
$W_{ij}(\pi)$	Waiting time preceding of job i on machine j in a job solution π
$W_i(\pi)$	Total waiting time of job i in a job solution π
r_i	Ready time of job i
$C_i(\pi)$	Completion time of job i in a job solution π
$F_i(\pi)$	Flowtime of job i in a job solution π
d_i	Due date for job i
w_i	Weight of job i
$L_i(\pi)$	Lateness of job i in a job solution π ($L_i(\pi) = C_i(\pi) - d_i$)
$T_i(\pi)$	Tardiness of job i in a job solution π ($T_i(\pi) = max\{L_i(\pi), 0\}$)