OPEN SHOP SCHEDULING PROBLEM: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Since Gonzalez and Sahni's seminal paper in 1976, Open Shop Scheduling Problems have received considerable attention over the last four decades. In that span, a wide range of articles regarding this machine environment has been published. These papers have dealt with many topics within this theme, like different optimality criteria and, or, job characteristics. To classify the academic production in that subject, both quantitatively and qualitatively, we present a systematic literature review framework for the Open Shop Scheduling. Based on the survey of seventy articles, we use six metrics in such classification, and we propose an original network representation of the gathered results, regarding optimality criteria. The primal goal of this paper lies in contributing to the construction of a more robust framework in Open Shop Scheduling and identifying underexplored fields in that matter to a lesser extent.

KEYWORDS: **Systematic Literature Review; Scheduling; Open Shop.**

AD & GP – PO na Administração e Gestão da Produção

IND – PO na Indústria

OA – Outras Aplicações em PO

1. Introduction

Scheduling is a highly critical area for the companies since its primary objective is to address the allocation of scarce resources to productive operations in a given period to optimize one or more performance indicators [Leung 2004], [Pinedo 2012].

Since the seminal work of [Johnson 1954], this field of knowledge has considerable importance within Operational Research (OR). In this sense, a wide range of books, journals, and articles correlated to Scheduling have been published, in which a wide variety of topics approached. Amongst these themes, perhaps the more important is correlative to the machine environment, that is, under which productive logic and flow pattern the jobs will be processed by the machines. Concerning this aspect, there are five environments in literature, namely, Single Machine Shop, Parallel Machine Shop, Flow Shop, Job Shop and Open Shop, the latter being the object of study of this article.

The Open Shop differs from other machine environments due to *à priori* unawareness regarding the processing route of jobs and tasks on the machines, which should be arbitrarily chosen by the scheduler. Despite being verified many applications of this type of productive logic in practice, as in mechanical shops, quality control centers, among others, there's a smaller number of publications related to this topic.

Notwithstanding, even with a lower number of publications, there's still a considerable number of studies dedicated to Open Shop found in the literature. Among them, there are those devoted to the synthesis of the study of this theme, through the recovery of prior publications considered as the best and most relevant by their authors. Such type of study is known as review article. When we built this kind of analysis in light of an objective set of criteria under which we categorize these studies it has what is called a systematic review, which we can find in related work to Health Sciences but little observed in the context of Engineering.

This paper brings a Systematic Literature Review regarding Open Shop Scheduling. From this angle, we use several metrics for the purpose of classifying the articles surveyed in journals with high relevance in OR.

2. Open Shop

Open Shop is a machine environment in which there are no restrictions respective to the processing route of each job during the production process [Pinedo 2012]. In this case, the construction of this path is carried out by the job processing and may differ between the jobs, being part of the decision-making about the sequencing activity [Chen et al. 1998].

In Open Shop Scheduling problem, a set of n jobs should be processed by a set of m machines. Each job contains a set of m operations, each of which processed on only one machine. In its classic form, a job has to be worked at most by one machine at a time, a machine processes at most one job at a time, and the order in which the operations of a specific job are processed is immaterial.

Such immateriality respective to the processing order of the operations makes these problems immensely combinatorial [Prins 2012] and provides a greatly larger solution space than its shop scheduling counterparts [Naderi et al. 2010].

The first work regarding Open Shop Scheduling is attributed to [Gonzalez and Sahni 1976], which deals with both preemptive and nonpreemptive cases of Open Shop, in which they intended to minimize the finish time. To meet this goal, they developed algorithms for the cases above of Open Shop, permeating considerations on the computational complexity too.

3. Systematic Literature Review

We will use the Systematic Literature Review (SLR) in our paper. SLR is defined as the process of gathering, knowing, understanding, analysis, synthesis and evaluation of a set of scientific articles to create the state-of-the-art about a given examined topic or subject [Levy and Ellis 2006].

Such methodological procedure is most commonly found in Health Sciences, as seen in the work [Avouac et al. 2006]. In this sense, the Cochrane Collaboration is an international reference in the construction and validation of systematic reviews.

We will base The SLR presented in this paper on the seven steps recommended by the Cochrane Collaboration [Higgins and Green 2011]. These steps are:

1. Defining the review question: In our work, the review question to be answered by this paper regards to the gaps in the literature of Open Shop Scheduling;
2. Location and selection of the studies: in this paper, we gathered seventy articles from journals ranked in the Q1 and Q2 tiers of SCIMAGO Journal and Country Rank, in the period between 1976 and 2015;
3. In this paper, we assess the seventy articles from the perspective of the following metrics:
    a. Year: This metric seeks to evaluate the quantity of Open Shop Scheduling articles published per year, by the search scope presented in step 2;
    b. Type: This metric assesses the type of the studied article. There are three types of articles, namely, specific problems, when the focus of the work lies in the presentation of a specific issue; algorithmic complexity articles, when the study primarily deals with computational complexity of the Open Shop problems; and comparison articles, when the article investigated studies the performance of the solving methods used by its author comparing them to instances of the literature or other related work. There are cases where the articles address more than one topic and are therefore classified in more than one category;
    c. Scheduling Class: in this category, the papers are categorized in off-line scheduling and on-line scheduling;
    d. Job Arrival Mode: the Open Shop will be divided in static or dynamic;
    e. Nature of the Data: here, the papers will be categorized in deterministic and stochastic, or deterministic/stochastic when the papers has both approaches;
    f. Optimality criteria: gamma field of Graham's notation.
4. Data collection: in this paper, this stage of the review was carried out jointly with step 3, which presents the metrics used in the categorization of Open Shop articles;
5. In this paper, three forms of graphical presentation were chosen, which they are:
    a. We present the results respective to the year, type, scheduling class, job arrival mode and nature of the data in tables and column charts;
    b. The analyses regarding optimality criteria will be shown via networks made in Pajek software for network analysis. We built these networks from the relation of each of the metrics and the articles under scrutiny.
6. Data Interpretation: in this paper, after the analyses carried out in step 5 considerations about unexplored or underexplored fields or gaps in Open Shop Scheduling in the articles belonging to this review will be made;
7. Improvement and updating of the review: in this paper, this step does not belong to the scope of this review.

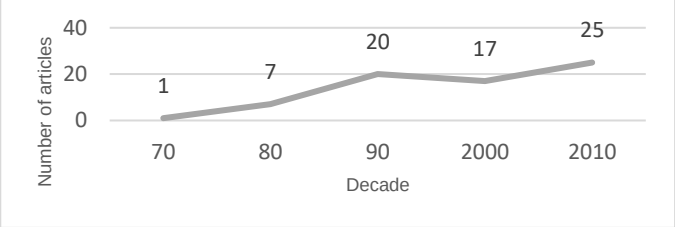
4. Systematic Literature Review of Open Shop Scheduling

In this section, it will be presented our Systematic Literature Review respective to the Open Shop Scheduling, by the steps aforementioned.

4.1 Year

This metric is addressed in this review to identify the historical evolution of Open Shop study, represented here in the number of articles published per decade. Figure 1 graphically represents this development.

Figure 1 Historical evolution of Open Shop Scheduling

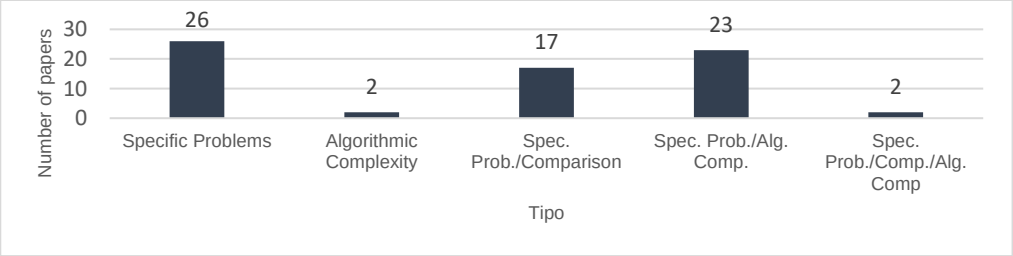


From the figure, we can verify that forty-two of the seventy reviewed articles were published from 2000. Although, the other multi-machine environments still receive more attention from researchers than Open Shop. One of the possible reasons for that occurrence lies on the greater solution space that Open Shop problems have, due to the arbitrariness of job processing routes [Noori-Darvish et al. 2012].

4.2 Type

About the type of article, we use three categories and their combinations. The results concerning this metric are presented in Figure 2.

Figure 2 Classification of Open Shop papers regarding the type



From Figure 2 it can be observed that the Specific Problems articles are those found in greater quantity, with twenty-six papers categorized in such classification. Among them, it can be highlighted the work of [Lawler et al. 1982] which deals with Open Shop with Parallel Machines.

At the other extreme are the articles that address exclusively the algorithmic complexity of Open Shop and the ones that deal with algorithmic complexity, comparison, and specific problems altogether, both types containing only two articles. Concerning the former, it can be highlighted the article of [Liu and Bulfin 1985] which address the complexity of preemptive Open Shops, while regarding the latter the study conducted by [Oulamara et al. 2013] about Open Shop with resource constraints is the most relevant in that category. In this work, the authors consider the algorithmic complexity, compare the results obtained by the heuristics used by them regarding performance and then, through an example, they do the application part of the article.

The studies which jointly treat specific problems and comparison or application and algorithmic complexity appear in an intermediate stage. For the first case, there's the paper of [Blum 2005], in which it works with the hybridization of beam search with Ant Colony Optimization. In this work, the author compares the results obtained by this hybridization with the results found through other solving methods, like Genetic Algorithms. For the second case, the initial work of [Gonzalez and Sahni 1976] is an excellent example of an article which brings in its core both the application as well as the algorithmic complexity.

4.3 Scheduling Class

As mentioned before, the categories related to this metric are on-line and off-line. It is considerably large the amount of off-line Open Shop studies if compared with their counterparts. From the seventy reviewed articles sixty-four deal with that type of scheduling class.

Concerning the other categories, it is necessary to mention them in more detail. Regarding papers that addressed the on-line scheduling (2 of 70), it can be highlighted the paper authored by [Zhang and van de Velde 2010]. In this study, the authors dealt with the on-line two-machine Open Shop with time windows between the completion of the first operation and the beginning of the second. The processing time of each operation of a given item is only known when the operation ends and the duration of the time window is unknown until the completion of its course.

Two papers compared both scheduling classes. The study of more relevance is the article of [Bai and Tang 2013], in which the authors compare the makespan found in the off-line case with that obtained in its on-line version, regarding the worst-case ratio.

4.4 Job arrival mode

The results respective to this metric attest the overwhelming predominance of static Open Shop. From the seventy surveyed papers, sixty-five of them are about this topic.

Regarding the other categories, there is only one paper that addressed both job arrival modes. In this article authored by [Guéret and Prins 1998], the possibility of job insertions or rescheduling is analyzed, which are based on a priority rank of the job processing times. When the static facet of the scheduling problem is studied, this priority rank is not updated. Thus rescheduling does not occur. In its dynamic form, the job priority rank is updated at each job allocation which leads to new schedules.

Concerning the articles that deal with dynamic Open Shop, which total four, it can be highlighted the work of [Naderi et al. 2010], which studied the job or task insertion in Open Shop, proposing insertion heuristics for it. These job or task insertions lead to new schedules. Such matter can be perceived as a proficuous theme for future research.

4.5 Nature of the data

Concerning the nature of the data, we divided the papers in deterministic, stochastic and deterministic/stochastic. Regarding the deterministic Open Shop, such category possesses the largest number of articles within the scope of this review with sixty-two publications. We observed in the analysis that algorithmic complexity articles mostly address a deterministic set of data. Among the papers that used deterministic data is the paper authored by [Bräsel et al. 1994], which tackled the unit-execution time Open Shop. In that type of Open Shop, all the operations of a given jobs last one-time unit (one second, for example).

Regarding papers that dealt with a stochastic and hybrid set of data, it can be observed that little has been published regarding this topics. On the former, with seven of the seventy studies herein classified it can be highlighted the paper authored by [Chung and Mohanty 1988],

in which is used Poisson distribution in the job arrivals and job processing times exponentially distributed. With regards to the latter, with only one paper addressing such nature of the data, the work of [Azadeh et al. 2015] deals with machine repair and failure times stochastically distributed, while other input data, as processing times, are deterministic. Such topics can be seen as productive ones regarding future research and work.

4.6 Optimality criteria

In this step of this review, the analyses and results are concerning the optimality criterion (gamma field in Graham's notation). We made in Pajek the network relating authors, and therefore papers, with the optimality criteria. The analyses are divided into four temporal strata: First Period, between 1976 and 1989; Second Period, between 1990 and 1999; Third Period, between 2000 and 2009; and Fourth Period, between 2010 and 2015.

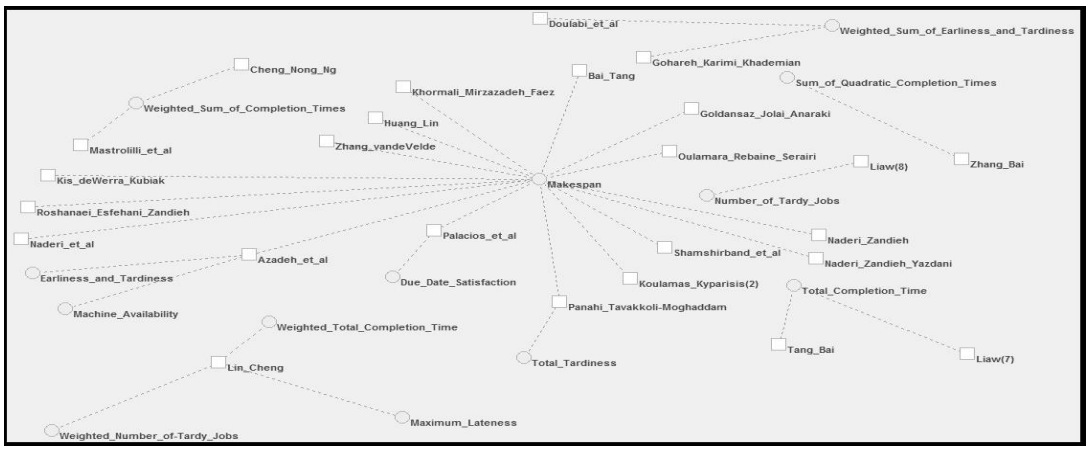
In the First Period, from the eight articles to this restricted temporal stratum, five of them deal with the makespan minimization. The other criteria addressed were the number of tardy jobs, in [Pinedo 1984]; the flow time, in [Pinedo 1984] and [Liu and Bulfin 1985]; and the sum of the completion times, tackled in the paper authored by [Liu and Bulfin 1987].

The Second Period brought more diversity regarding optimality criteria that had not been studied in the past decades. Maximum Lateness, which was examined by [Kellerer et al. 1995] and weighted number of tardy jobs, dealt with in the articles of [Galambos and Woeginger 1995] and [Brucker et al. 1993] are examples of objectives studied for the first time in this period. Another aspect relevant to the analysis of optimality criteria in the 1990s is the considerably large number of articles regarding the makespan if compared with the other optimality criteria.

The Third Period marks the prevalence of makespan as the most used optimality criteria persist. The other optimality criteria, like total tardiness, addressed by [Liaw 2004], or flow time, treated in the paper authored by [Gupta et al. 2003]. In relation to the latter, it is important to emphasize that this article deals with more than one optimality criterion simultaneously and concurrently, because, in addition to the flow time, the authors also address the makespan as well.

In the Fourth Period, there is an increasing diversity of optimality criteria approached. Some of these optimality criteria that have not been studied yet include the sum of earliness and tardiness, which is found in the article of [Azadeh et al. 2015]; the sum of quadratic completion times, present in the article of [Zhang and Bai 2014]; and so on. Despite the increasing diversity aforementioned, makespan continues to be, by far, the most studied optimality criterion. Figure 4 brings the network made in Pajek regarding that period. The squares represent the authors, and, by extension, the papers, while the circles represent the optimality criteria by them addressed.

Figure 4 Optimality criteria in the Fourth Period



In short, it can be noted that makespan is widely studied over the decades assessed by this systematic review. One possible explanation for that occurrence lies in the relation between makespan minimization and throughput of the constructed schedule. As the throughput is the number of finished jobs per time unit, the throughput maximization is obtained via makespan minimization [Baker and Trietsch 2009]. With regards to the other optimality criteria, like the number of tardy jobs or considerations about machine availability, there's a fertile field to be explored in future work and research.

5. Conclusion and future research

We conceived the review presented in this paper to identify possible literature gaps or underexplored fields, concerning to future work and research related to Open Shop. After the conclusion of the analyses of the metrics used in the proposed categorization, we verified that the Open Shop field of knowledge requires more attention and papers which deal with the dynamic, on-line scheduling. With a hybrid set of data, with optimality criteria that differ from makespan minimization.

At the same time, this paper could identify that the major attention is devoted to solve the basic form of the problem. Due to its high combinatorial complexity level, the main academical focus remains on algorithmic performance, conditioning the applications and extensions out of the Open Shop kernel. In this sense, advances in this field can contribute to shortening the gap between the theoretical issues and the shop floor and real-life problems.

Moreover, we introduced to the Scheduling field of knowledge the network representation of the gathered results in the optimality criteria category of the proposed systematic literature review. The main advantage of this graphical presentation lies on the ease of understanding the links between authors and optimality criteria by them approached. Furthermore, such network enables us to clearly identify underexplored areas of study, which can be fruitful for future research and work.

Regarding the proposed framework for a systematic literature review of Open Shop, it can be studied in future works the application of this framework for the other machine environments, like Flow Shop or Job Shop. Moreover, future contributions to this topic are two-fold: the proposed framework can encompass more criteria, like job characteristics and, or, solving methods, and the network representation can be easily extended to the other criteria.

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