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Invited Review

A common framework and taxonomy for multicriteria scheduling problems with interfering and competing jobs: Multi-agent scheduling problems

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ABSTRACT

Most classical scheduling research assumes that the objectives sought are common to all jobs to be scheduled. However, many real-life applications can be modeled by considering different sets of jobs, each one with its own objective(s), and an increasing number of papers addressing these problems has appeared over the last few years. Since so far the area lacks a unified view, the studied problems have received different names (such as interfering jobs, multi-agent scheduling, and mixed-criteria), some authors do not seem to be aware of important contributions in related problems, and solution procedures are often developed without taking into account existing ones. Therefore, the topic is in need of a common framework that allows for a systematic recollection of existing contributions, as well as a clear definition of the main research avenues. In this paper we review multicriteria scheduling problems involving two or more sets of jobs and propose an unified framework providing a common definition, name and notation for these problems. Moreover, we systematically review and classify the existing contributions in terms of the complexity of the problems and the proposed solution procedures, discuss the main advances, and point out future research lines in the topic.

1. Introduction

The existence of several objectives is consubstantial to scheduling problems, as it can be seen from different definitions of the field, such as Pinedo (1995), where scheduling is defined as a decision-making process that has as a goal the optimization of one or more objectives. Therefore, it is not surprising that multicriteria scheduling problems have been widely studied in the scheduling literature (see e.g. the reviews by Hoogeveen, 2005; Minella, Ruiz, & Ciavotta, 2008; T'kindt & Billaut, 2001, 2002). In all the problems analyzed in these surveys the criteria considered affect all jobs to be scheduled. Only Hoogeveen (2005) mentions the case of *multicriteria scheduling problems with two or more sets of jobs*. In these problems, two or more sets of jobs (not necessarily disjoint) have to be scheduled, each one with its own objective(s). Although this is a special case of multicriteria scheduling problems, the existence of several sets makes the problems rather different than their one-set counterpart as, in general, the complexity of these problems changes even if the objective functions are the same (Agnetis, Mirchandani, Pacciarelli, & Pacifici, 2004).

As discussed later in this paper, this type of scheduling problems arise in a number of real-life applications and therefore have been subject of interest by researchers and practitioners in the last few years. However, the lack of a unified framework has been a major deterrent for research advances in the field. There is not even a common name which has caused some contributions to ignore past works on the topic, as the keywords and title of the existing results make it difficult to conduct an extensive search (for instance, the same conclusion regarding a specific problem is independently shown by Agnetis, Pacciarelli, & Pacifici, 2007a,chap. 2; Nong, Cheng, & Ng, 2011). Without a common definition and name, the notation and limits for this kind of problems are not clear, which may have hidden valuable contributions and makes the comparison among similar problems very difficult. In addition, this has caused that some scheduling problems dealing with two types of jobs, but with no interference among them, were considered part of the topic. For instance, in some problems described in Leung, Pinedo, and Wan (2010), the jobs in one set have their due date to be equal to their release date plus their processing times. Therefore, these jobs have to be processed in a specific (fixed) time interval and the remaining scheduling problem is how to schedule the jobs in the other set, which can be assimilated to a traditional scheduling problem with machine unavailability.

In this paper we will try to move towards an unified view on the topic that allows overcoming the above problems. More specifically, we (1) discuss the different definitions and approaches for the problem and provide a framework consisting of a single

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definition and notation, (2) give some complexity results and general properties, (3) review and classify the different contributions and results on the topic based on the aforementioned framework, and (4) point out the main research avenues in the field. By doing so, we expect to foster the research in this interesting and challenging scheduling area.

The remainder of the paper is structured as follows: Section 2 discusses the problems, their applications and the different names used in the literature. In Section 3 we present the notation and adapt the taxonomy presented by T'kindt and Billaut (2002) for multicriteria scheduling problems. The relationship among the complexities, single criteria and multicriteria scheduling problems is outlined in Section 4, where some general properties are presented as well. Literature is reviewed by classifying the problems into basic problems (discussed in Section 5) if there are no conditions for the machines or jobs, i.e. the most general case indicating only the machine environment and the objectives considered for each set of jobs; and extended problems (discussed in Section 6), where specific conditions are imposed. Finally, Section 7 contains the conclusions and future research lines.

2. Fields of application and problem definition

We consider two or more set of jobs – not necessarily disjoint – competing or using common processing resources (machines). Each set of jobs has one objective, which may or may not be the same for each set. The objectives of some sets have to be optimized while others have to satisfy one or more constraints. This type of scheduling problems arise from many real-life fields of application (see Mor & Mosheiov, 2010):

- *Supply chain scheduling*: In a supply chain, a classical problem is to minimize overall manufacturing and distribution costs integrating production and delivery. If the customers are competing for a common processing resource then the problem implies interfering jobs. Fan (2010) presents a scheduling problem where the customers are placed at different locations such that delivery times are given. The objective is to minimize the sum of time between job's release and the delivery to the corresponding customer.
- *Rescheduling*: Rescheduling can be defined as the process of updating an existing production schedule in response to disruptions or other changes (Herrmann, 2006, chap. 6), such as the arrival of new jobs to be processed. Rescheduling usually implies more than one set of jobs, so a standard rescheduling problem can be formulated as a two-agent scheduling problem (Leung et al., 2010). In this problem there are usually two sets of jobs: existing jobs which have been already scheduled and new jobs to be scheduled. In this problem, two cases may be distinguished (Pinedo, 1995):
  - The starting times of the existing jobs cannot be modified ('frozen' jobs), so the problem can be considered as a single criteria problem subject to machine/job availability constraints (see e.g. Perez-Gonzalez & Framinan, 2009, 2010a; Perez-Gonzalez, Framinan, & Molina Pariente, 2011).
  - The starting times of the existing jobs can be modified (existing jobs can be rescheduled). If the same objective is considered both for existing and incoming jobs, the problem is again a scheduling problem with one set of jobs. However, in many situations it makes sense to employ different objectives for each set: Some performance measure is minimized for incoming jobs in order to obtain a short completion time for this set of jobs (e.g. minimizing their makespan or flowtime), while the objective for the existing jobs aims to minimize the disruption from their initial schedule. The usual way to achieve the latter objective is either to minimize their tardiness or impose that these jobs cannot be tardy (see e.g. Perez-Gonzalez & Framinan, 2010b; Unal, Uzsoy, & Kiran, 1997); or to consider special disruption measures as the differences between the completion times of the old jobs in the sequence before rescheduling and the new sequence (such as in e.g. Hall & Potts, 2004; Mu & Gu, 2010; Yuan & Mu, 2007; Yuan, Mu, Lu, & Li, 2007).
- *Telecommunications*: Packet-switching networks usually support different applications, each one requiring the transmission of data packages that must reach their destination within some time limit. The most important performance objective for some applications (such as file transfer or interprocess communication) is not to exceed certain mean delay, while for other applications (such as voice or video) is to achieve a specific loss rate. Therefore, the idea of several sets of jobs (packets belonging to applications) that must compete for the use of the same resource (the bandwidth) arises naturally. This problems have been addressed by Peha and Tobagi (1990), Peha (1995), and Meiners and Torng (2007). A similar problem is found in Arbib, Smriglio, and Servilio (2004) for internet protocols, where one user wants to maximize the on-time packets transmitted to other user, while guaranteeing certain amounts of on-time packets to a third user.
- *Maintenance scheduling*: Some references in the literature address problems about scheduling jobs and preventive maintenance simultaneously (see e.g. Cassady & Kutanoglu, 2003; Ruiz, Carlos Garcia-Diaz, & Maroto, 2007), considering only one criteria for the jobs. However, since production and maintenance have common resources (the machines) and their activities are actually often conflicting, integrated production and maintenance cooperative scheduling is an example of interfering job problems when we consider a multiobjective approach. Khelifati and Bouzid-Sitayeb (2011a) simultaneously address the problem of scheduling production and preventive maintenance operations, taking into account both production and maintenance criteria. Since most machines have to be maintained at regular intervals (i.e. they require given periods of time on each machine), maintenance tasks can be modeled as *maintenance jobs* to be scheduled along with *production jobs*. Since maintenance tasks have to be performed within a time window, each maintenance job has both a release date and a due date (representing the earliest and latest time for the task, respectively). The natural objective for scheduling the set of maintenance jobs is thus to minimize a function of the deviation from their release and due dates, while production jobs are scheduled to minimize some performance measure. This approach is adopted by Wan, Vakati, Leung, and Pinedo (2010). Kellerer and Strusevich (2010) give an interpretation of their specific interfering job problem where machine(s) is(are) subject to a compulsory maintenance during the planning period, the length and the deadline of the maintenance operations are given, and the Decision Maker has to decide when to start the maintenance period, while an objective related to the jobs has to be minimized.

It is to note that, there are several papers focusing on game theory aspects of the problems and its applications in industrial management, project scheduling, queuing setting, telecommunication services, economic markets, scheduling of trains, etc. These papers are originally cited in Agnetis, Mirchandani, Pacciarelli, and Pacifici (2000), Agnetis et al. (2004, 2007a, chap. 2), and Agnetis, Pacciarelli, and Pacifici (2007b), and they are subsequently cited often by authors dealing with interfering jobs scheduling problems, but it is to note that problems addressed there are not