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A review and classification of computer-based manufacturing scheduling tools

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ABSTRACT

Computer-based manufacturing scheduling tools can play a key role in the management of industrial operations, as obtaining economic and reliable schedules is at the core of excellence in customer service and of efficiency in manufacturing companies. As a consequence, this topic has been receiving an increasing interest in the last decades, resulting in a number of case studies and descriptions of implementation of these tools. However, to the best of our knowledge, there is no review of these cases in order to classify existing references and to identify relevant issues still not properly addressed. Therefore, in this paper we carry out a systematic review of case studies of manufacturing scheduling tools. In order to provide a coherent taxonomy for the analysis of these tools, we develop a classification based on the functionalities of the manufacturing scheduling tools. Using this framework, existing contributions are classified and discussed, and a number of conclusions and open issues are identified. We hope that our work can establish a coherent picture of the topic so it serves as a starting point for future research.

1. Introduction

Scheduling –understood as the assignment of the various resources of a company to the manufacturing of a range of products (Framinan, Leisten, & Ruiz, 2014) – plays a crucial role in industrial companies. Given the complexity of scheduling decisions, it is usually carried out using a piece of software to provide some type of support to the human user. This software is denoted here as *Manufacturing Scheduling Tool*. Although a number of case studies and descriptions of implementation of manufacturing scheduling tools is available in the literature, there is a great variation regarding the functionalities of this software, ranging from relatively simple applications focused on a specific problem, to sophisticated information systems capable of supporting a wide range of scheduling decisions. This variability, coupled with the specific nature of scheduling, makes difficult to have a coherent picture of the developments in the area, which in turn hides both specific topics not yet addressed and issues already solved in a satisfactory manner.

The goal of our paper is to systematically review these scheduling tools and to provide a framework for their classification. We focus on what we call the **structure** of these tools, i.e. which are their functionalities and how these functionalities are organized. In this way, we investigate what these tools are made for rather than focusing on how these functions are achieved. Although it would be undoubtedly interesting to study which techniques and/or methods are employed, we believe that a first step is to establish what these tools are made for. To the best of our knowledge, there are no other reviews on the use of computer tools for scheduling in manufacturing settings. Furthermore, the few reviews on other computer-based decision support tools (see e.g. Yarramsetti & Kousalya, 2015 or Kreipl & Pinedo, 2004) usually address the techniques and/or methodologies employed in the tools rather than focusing on the structure of these tools. By doing so, we expect to present an exhaustive state-of-the-art of manufacturing scheduling tools that serves to identify a number of relevant issues still not properly addressed and to provide a retrospective study on the parts that constitute manufacturing scheduling tools implemented in practice. Additionally, since the lack of an integrated view of scheduling has been frequently mentioned (see e.g. Herrmann, 2004) as a cause of the well-known gap between research and practice in the scheduling field (MacCarthy & Liu, 1993), we expect that the findings in this paper also serve to foster research in some areas where actual scheduling tools do not offer a satisfactory solution due to the lack of basic research.

The review carried out in our paper shows a field in which great advances have been accomplished, but also where some mis-

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matches between research and practice are revealed (such as e.g. the scarce practical relevance of well-established theoretical scheduling objectives), scientific challenges are identified (such as e.g. to advance in a proper incorporation of human expertise), and research opportunities are devised (such as e.g. the needs for more research in layout modeling issues). The remainder of the paper is as follows. In Section 2 we briefly discuss the main issues regarding manufacturing scheduling tools and their structure in order to present the framework to classify existing contributions on the topic. In Section 3 we present the results of the classification of the manufacturing scheduling tools. Finally, in Section 4 we conclude and discuss a number of open issues that emerged through the analysis.

2. The structure of manufacturing scheduling tools

Although manufacturing scheduling has been carried out manually for years (Metaxiotis, Psarras, & Askounis, 2002), the necessity to overcome the limited short-term and long-term memory of human planners (McKay & Wiers, 2003), particularly when they have to consider many constraints at the same time (Speranza & Woerlee, 1991) has led to the development of different types of computer support for decision making. These systems are collectively known as manufacturing scheduling tools, and include very different types of software, going from interactive systems that allow an automatic check of the feasibility of schedules, to sophisticated systems where optimal schedules are suggested.

Given such variety, it is necessary to develop a framework to classify the different contributions regarding these tools. Since they constitute a special type of business information systems (Framinan et al., 2014), they can be described along a list of *functionalities* or pieces of business functions that the system is capable to support. In other words, the functionalities describe which manufacturing decisions are supported by the system. These functionalities and the way in which they are organized is what it is called in the remainder of the paper *structure* of the tool and will serve to distinguish the different features found in the tools described in the literature.

Clearly, as many tools described are company-specific, it is necessary to distinguish between specific functionalities (unique for each software application) and those which are common to most tools and that constitute the *architecture* of the system. The work by Framinan and Ruiz (2010) presents a classification of the generic (i.e. high-level) functionalities of a manufacturing scheduling tool. Therefore, we can use this classification as a starting point although, given its abstract nature, a modification and extension of the classification is required. In addition, since our review is based on actual descriptions of manufacturing scheduling tools, some categories present in the architecture are not found in practice.

The procedure adopted for this review consists of two stages. In a first stage, a systematic review was developed for papers published from 2000 to 2016. Given the processing and graphical capabilities of computers prior to that date, we first focus on that period. We used the SCOPUS search engine by Elsevier, given that the majority of relevant journals and conference proceedings are indexed in this database. Different queries were performed to take into account as many tools as possible. To do so, we also used different definitions of systems commonly employed in scheduling practice, such as Decision Support Systems, or Expert Systems. The queries used for the review are shown in Fig. 1 together with the number of results obtained.

Due to the heterogeneity and ambiguity of the results of the first stage, some of them were not suitable for our study. Therefore, we adopted a three-step procedure to filter the results:

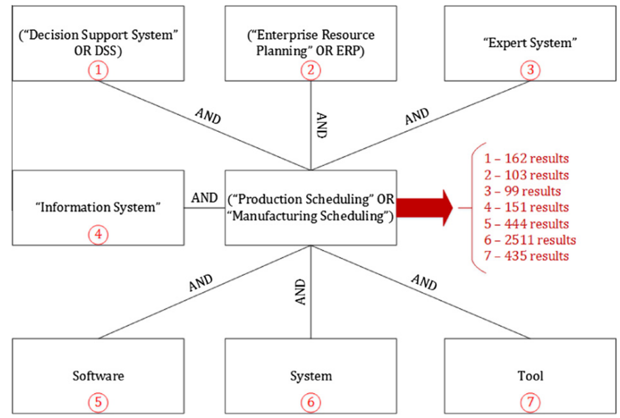

Fig. 1. Review queries and summary of the results.

- Title. First, we rejected those works whose title was not relevant for our study.
- Abstract. The abstracts of works that seemed to be relevant were carefully read and those that did not focused on the topic were excluded.
- Full document. Those works still remaining were analyzed in full-depth in order to obtain the final set of contributions for the review.

In a second stage we extended the number of contributions by selecting all relevant references cited by the works in the first stage, including references prior to 2000. To filter theese new contributions, we adopted the same three-step procedure as in the first stage. Moreover, we include book chapters that were not considered in previous stage, but that were listed in the references selected in the second stage.

As a result of the analysis of the final set of references, a number of types of functionalities were identified. These types constitute the framework for classification (see Fig. 2), and are discussed in the following subsections.

2.1. Problem modeling

This type of functionality refers to the ability of the tool to capture in an autonomous or semi-autonomous manner different parameters of the corresponding shop floor. The following functionalities within this type are considered:

2.1.1. Model Detection (MD)

This functionality refers to the ability of the tool to determine the most suitable (abstract or theoretical) scheduling model from the raw instance data provided to the system. Since some theoretical scheduling models can be seen as simplification of a real-life setting, model detection might be seen as a type of constraint abstraction. However, since it focuses on a specific type of relaxation (i.e. that to reach to specific scheduling models so solution procedures taken from these models could be applied), we keep it apart. Model detection is achieved by the tools reviewed using different approaches:

- **Reduction Trees (RT).** Reduction trees constitute a useful taxonomy for scheduling problems, as they establish the interdependences for well-known scheduling problems together with their corresponding scheduling algorithms. Therefore, if the user enters the type of scheduling problem to be solved, it is possible for the tool to look for the stored algorithms which are closest to this problem according to the reduction tree.