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## Machine scheduling problems in production: A tertiary study

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### ABSTRACT

This paper presents the results of a comprehensive and systematic review of 129 literature reviews on machine scheduling problems in production (MSPP). The paper first proposes a conceptual framework that considers the main attributes of MSPP in seven categories and 75 sub-categories. After a descriptive analysis of the sampled papers that give insights into publication patterns for MSPP, a quantitative analysis of the sampled review papers is carried out based on the proposed framework. A synthesis of research findings describes the state-of-knowledge and unveils general deficiencies of literature reviews on MSPP. In addition, the paper provides a comprehensive overview of MSPP, which supports researchers in positioning their own work in the literature and in finding potential innovative research areas. The paper concludes with an outlook on future research opportunities in the area of MSPP.

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## 1. Introduction

### 1.1. Machine scheduling problems in production

Scheduling can generally be defined as the process of assigning restricted resources to a set of tasks that need to be accomplished. Scheduling is a relevant problem in many different areas, e.g. in project management (Leyman & Vanhoucke, 2015; Nkasu & Leung, 1997), software optimization (Li, Singhoff, Rubini, & Bourdellès, 2016), and personnel management (Cochran, Chu, & Chu, 1997; Prot, Lapègue, & Bellenguez-Morineau, 2015). Among the most prominent and important research fields in scheduling are production systems (Pinedo, 2008), which is also the focus of the paper at hand. In many production systems, jobs (that represent tasks) need to be processed on machines (that represent resources). The aim of machine scheduling problems in production (MSPP) is to find a sequence of jobs to be processed on machines in a way that optimizes a set of objective(s) without violating any of the constraints (Graves, 1981; Sen & Gupta, 1984). Even in modern production systems, such as in semiconductor manufacturing plants, scheduling techniques play an important role in reducing idle times, speeding up the production process and reducing cost by improving operational processes (Mönch, Fowler, Dauzère-Péres, Mason, & Rose, 2011).

As MSPP need to be solved in almost any production system to plan operational activities, related solution approaches are broadly applicable in practice (Tuncel & Bayhan, 2007). Solving MSPP is challenging in most cases, however, as modifying one simple assumption often leads to a new problem that requires new solution approaches. This fact renders MSPP not only a challenging problem for practitioners, but also a popular research topic for academia. It is thus not surprising that MSPP belong to the most frequently studied optimization problems in management and engineering. Simple database searches may illustrate the scope of this research stream: The keyword combination “scheduling” and “production”, for example, leads to about 1,750,000 hits in Google Scholar and 48,000 hits in Business Source Premier,<sup>1</sup> which gives an impression of the high number of publications in this area.

The continuous high publication output on MSPP makes it necessary to regularly synthesize and consolidate research topics and findings to give researchers and practitioners an overview of the existing state-of-knowledge and to identify research gaps that could be addressed in future research efforts. This general understanding already inspired many researchers to review specific sub-domains of this research field (see, for example, the meta-survey of Gorman (2016) on literature reviews in operations research and management science). Specific MSPP literature reviews help researchers to gain insights into the topic covered by the review, but they may also contribute to a loss of overview of the research domain itself (here: MSPP), whose state-of-knowledge may be scattered over a large number of specific review

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papers. As the high number of published works on MSPP prohibits a single review that covers the entire (primary) literature, one established way to synthesize research in this area is to conduct a tertiary study on a comprehensive sample of review papers (secondary works) on MSPP.

The next section gives an overview of tertiary studies and their contribution to the literature and outlines the contribution of the present paper to the literature on MSPP. Section 1.3 then outlines the organization of this paper.

### 1.2. Tertiary study

Research streams that enjoyed a high publication output in the past often suffer from the fact that the high amount of published research makes it very difficult (if not impossible) to maintain an overview of the entire domain. For the same reason, reviewing the entire domain in a single literature review is often prohibitive. Tertiary studies (i.e., reviews of literature reviews) may support structuring and synthesizing a research area in this case, as their object of analysis are (fewer) literature reviews instead of a prohibitively large number of primary research papers. The primary objective of tertiary studies is to investigate core themes that have been studied in a particular research area by reviewing and analyzing secondary works (i.e., literature reviews). The aims of tertiary studies are to (I) give an aggregated overview of a research domain, to (II) analyze research trends in the domain of interest, to (III) evaluate the methodological rigor of literature reviews in the domain, and to (IV) identify research gaps (on the secondary and, if possible, also on the primary level). Tertiary studies usually apply a systematic literature review to a sample of literature reviews, and they are an established research methodology in many different areas including operations and production management (e.g., Bushuev, Guiffrida, Jaber, & Khan, 2015; Glock, Grosse, & Ries, 2014), supply chain management (e.g., Hochrein & Glock, 2012; Hochrein, Glock, Bogaschewsky, & Heider, 2015; Kache & Seuring, 2014; Seuring & Gold, 2012), or software engineering (e.g., Garousi & Mäntylä, 2016). Tertiary studies provide a compact and comprehensive overview of the state-of-knowledge in a specific research area, and unveil general deficiencies of published literature reviews on the subject under consideration. Tertiary studies are thus valuable sources for finding potential areas for future research.

In the area of MSPP, a prohibitively large number of primary works and a high as well as an increasing number of secondary research motivated the tertiary study at hand. The tertiary study enables us to analyze the entire domain of MSPP, which would not be possible in a regular literature review that analyzes primary works (Garousi & Mäntylä, 2016; Hochrein et al., 2015). The contribution of an easy-to-understand but comprehensive overview of the vast research field of MSPP provided by our tertiary study is manifold. First, our paper gives a broad overview of the research field of MSPP and synthesizes findings that were obtained in literature surveys covered in our sample. As a review of the MSPP on the primary level is not possible due to the massive number of papers that have been published on this topic, only a tertiary study is able to review this research stream in such a broad manner. To the best of our knowledge, our paper is the first and only work that applies a systematic tertiary analysis to MSPP, so it is the only paper that gives such a broad overview of research on MSPP. Secondly, we develop a content-related and technical classification framework for MSPP based on an in-depth analysis of the sampled review papers. This framework for classifying MSPP (Section 3) can be seen as a synthesis of the different classification schemes for MSPP applied or derived in the sampled literature reviews. Thirdly, the content-related analysis (Section 4.3.2) illustrates major topics and applications that were discussed in the sampled review

papers, which helps readers in gaining insights into the topics that were emphasized by prior research (and, in return, into topics that did not receive much attention so far). This, in turn, assists readers in identifying possible avenues for future research or positioning their own work in the existing literature. For readers interested in conducting a secondary study on their own, this tertiary study helps to identify areas where a new or an initial literature review is required. The latter aspect is supported in detail in our content discussion that identifies topics where secondary studies are required in the future. Finally, this tertiary study could also serve as a guideline for the application of systematic review techniques in the area of MSPP, which is an aspect that is of increasing relevance in the scientific literature.

### 1.3. Organization of the paper

To accomplish the objectives outlined in Section 1.2, this paper, first, generates a sample of literature reviews on MSPP in a systematic search of the literature (Section 2). Subsequently, the paper proposes a comprehensive conceptual framework that reflects the main characteristics of MSPP in seven categories and 75 sub-categories (Section 3). The framework is used to evaluate literature reviews in this area. The methodology of the tertiary study is explained in detail in Section 4.1. After a descriptive analysis of the sample that gives insights into publication patterns (Section 4.2), a quantitative and content-related analysis of the sampled review papers is carried out (Section 4.3). This step contains an evaluation of the review methodology as well as a content examination of the sampled review papers based on the proposed framework to identify the most popular streams of research on MSPP. Finally, the study identifies methodological drawbacks of existing literature reviews on MSPP and highlights areas where future research might be promising (Section 5). Section 6 concludes the paper. Fig. 1 illustrates the steps of the tertiary study.

## 2. Review methodology

### 2.1. Literature search strategy

Tertiary studies require a rigorously developed literature sample to ensure that readers are able to reproduce sample generation and evaluation. As a result, tertiary studies require a systematic, well-structured and documented search of the literature (Hochrein et al., 2015). In the following, we describe the search strategy that was used to identify literature reviews on MSPP in detail. The literature search was conducted in November 2016. In a first step, keywords were defined that were later used to identify relevant works in the literature. The final keyword list was generated using three groups of keywords, where group A contained keywords related to scheduling (“scheduling” and “sequencing”), group B keywords that limited the search to MSPP (“machine”, “shop”, “manufacturing”, “production”, “process”, “flow shop”, “job shop”, and “open shop”), and group C keywords related to literature reviews (“survey”, “review”, “overview”, “taxonomy”, and “trends”). The keyword “shop” was included in group B to ensure that different spellings of shop-related production systems are covered (e.g., “flow shop” is often also referred to as “flowshop” or “flow-shop”). The final keyword list was generated by combining all keywords from the three initial lists. The database Scopus was then searched for works that contain keywords from the final keyword list either in their title, abstract or list of keywords. In this step, 7253 papers were identified. The database search was complemented by a forward and backward snowball search, where the references of papers contained in the sample were checked, and where works that cited papers contained in the sample were

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