

Sequencing Problems in Flow Shop Production Systems

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Abstract

Nowadays, customers are increasingly demanding more from products in terms of quality, flexibility, and delivery performance, while the price may hardly change due to many competitors. These requirements create a certain pressure on individual companies if they would like to hold their own in the competitive environment. Due to the constantly changing requirements, it is important for companies to identify certain potentials at an early stage and to adjust production accordingly. In the area of production, sequence planning is an important optimization tool that can be used for different objectives. It forms the foundation for detailed planning in companies and specifies the sequence of products to be processed. This paper deals with the topic of sequence planning in flow shop production. In the context of this, production planning and control are first discussed, as well as the areas of application of sequence planning. Subsequently, the basic models and the currently used methods are explained in more detail. To be able to give an outlook on future research directions in this area, an investigation of several current publications is carried out at the end. The knowledge gained from this work is intended to provide a quick overview of sequence planning and its application in flow shop production systems.

Keywords

Flow Shop Production, Production Planning and Control, Sequencing Problem, Smart Logistics, Logistics 4.0

1. Introduction

Nowadays, companies are faced with constantly growing demands to survive in the global competitive environment. In the recent past, new management concepts for production have been developed again and again. These concepts should make it possible to adapt production to the constantly increasing demands in the areas of time, efficiency, quality, and flexibility (Syska 2006). There are various approaches to be able to ensure this adaptation. One possibility is to reduce the number of employees in production, which is achieved through the increased use of robots and machines. However, this approach has a very high capital investment as a hurdle and can therefore not be implemented equally by all companies (Heger 2014).

In this context, another option would be to increase the value added to the production process. According to Günther and Tempelmeier (2009), this can be achieved through various factors. Among other things, they deal with the factors of time, quality, and flexibility. The creation of a product runs through the entire company and passes through the areas of procurement, production, assembly, and distribution. The individual areas need a certain time to carry out their activities. If the lead time of this entire production route is now lower, a higher creation of value can be achieved with the available resources. This lead time can be influenced by various factors and depends on the individual areas. However, when reducing the lead time, attention should also be paid to the quality of the process and the final product. One factor that is becoming increasingly important is flexibility. From a strategic point of view, production systems should be adapted to long-term changes in the market. At the same time, it should be possible to respond to customer requirements and adapt the production program at short notice (Günther and Tempelmeier 2012). The task of operational production planning and control is to contribute to the exploitation of individual performance potentials. A subarea of this is sequence planning or detailed scheduling. This determines the sequence in which the orders are processed on the individual machines. This sequence has a major influence on various parameters such as capacity

utilization, and idle times, but also on the throughput time in production (Latz 1997). Sequence planning in shop floor production has a high level of complexity. The different machine sequences and working times of the individual products lead to various problems when optimizing the sequence. Due to the high complexity and the many possible combinations, this problem is declared one of the most difficult to solve in production planning. The great individuality of production makes it difficult to define the best solution for this problem. When searching for methods to solve this problem, one quickly realizes that there is a multitude of different approaches. The problem is that there is hardly any literature that summarizes all or most of these possibilities and specifically addresses sequencing in shop floor production. Most sources deal only with sub-areas or individual procedures. Due to the previously discussed challenges, this paper aims to show the current state of research as well as the methods currently used for solving sequence planning in flow-shop production systems. Moreover, the authors present a systematic literature analysis (SLR) on the state-of-the-art regarding sequence planning approaches in flow-shop production systems. Finally, this paper discusses the research findings, concludes the topic, and gives implications for both, research, and practical implications.

2. Theoretical basics of production planning and -control

In this section, the authors discuss the historical development of production planning and -control systems (PPS) and focus on the deduction and explanation of the target system of PPS, later on.

2.1 Historical development of production planning and -control systems

In the 1960s, a shift in individual productions began to take place. At that time, the markets were unsaturated and little attention was paid to customer-specific wishes. In these years, the saturation of the markets increased, and companies began to respond more closely to customer wishes. As a result, the number of products, as well as variants, increased, and productions had to adapt structurally due to this increase. Due to the integration of customer-specific requirements, the degree of complexity of production increased, which until then had mainly involved linear processes and could still be manually controllable or plannable (Adam 1992). Due to the advancing use of computer technologies, the term Material Requirement Planning, which is also referred to as MRP or MRP1, has also been in existence since the 1960s. This deals with the determination of requirements, storage, disposition, and provision of the necessary parts required for production. MRP1 is planned based on a fixed production program, which in turn is based on the material requirements of the sales orders. Consequently, the primary requirement is specified by the sales market. The dependent requirements (assemblies, individual parts) are consequently determined from the BOM explosion and thus only the quantity is planned (Hartrampf 2020). In the 1980s, materials and time management in production was summarized under the term production planning and control. Since then, the term has become established in both academic research and corporate practice, and it is hard to imagine life without it. In addition, the term serves as a link between the two fields, each benefiting from the knowledge gained by the other. The target object of PPS at that time was the entire production including all areas that are indirectly involved, such as design. Since then, the concept of PPS has been constantly expanded (Schuh and Stich 2012). Since the beginning of the 1980s, attempts have been made to create a combination of technical and business information processing. The result was an integration of the logistical or business management components and the technical components for product manufacturing. This combination resulted in the common, cross-functional use of databases, which gave rise to Computer Integrated Manufacturing (CIM), in which production planning and control form the link between the two areas (Hartrampf 2020). Although nowadays the term ERP (Enterprise Resource Planning) is often used, the PPS keeps its important meaning. Here it is to be seen that the ERP like the SCM (Supply Chain Management) is further on the evolution path. Both are concerned with quantity and capacity planning via production, including upstream and downstream areas. Nevertheless, the focus is still on the planning of resources and production processes, just as they were already defined in the PPS term. In the meantime, research has shown that the requirement profile of manufacturing companies has evolved and that the industrial environment is also important for contemporary production management. It is becoming increasingly clear that the previous use of the PPS term covers, at best, only a fraction of what is used today, the "core PPS". Research shows that the planning of in-plant production and order fulfillment operations are dependent on the entire value chain and that the entire supply chain must be considered for optimizations (Schuh and Stich 2012).

2.2 The target system of production planning and -control systems

Production planning and control aim to determine the material flow in such a way that, considering the production capacities, the orders are manufactured in such a way that all delivery dates are met. Nowadays, this planning can only be managed by computer-aided information systems, since the complexity and the number of data, which must be processed for the planning, are continuously increasing (Höck 1998). In addition to choosing and applying the right

production planning method, the structure of the production process must also be analyzed to arrive at the correct solutions. Due to the diversity of real production systems, a typification cannot be based on a single aspect. For this purpose, several aspects are considered, thus enabling comprehensive characterization of the production process. To be able to realize such a meaningful characterization, the production should be subdivided as follows:

- Factor-related properties
- Product-related properties
- Process-related properties

The factor-related properties specify how a large part of the costs are arises. Examples of this are labor-intensive production, in which labor costs form a high proportion of the production costs. In other production situations, expenses that cannot be directly allocated to the production process predominate. allocated in the production process. Examples of this are Cosmetics, which represent advertising-intensive production. There are large costs for advertising and packaging. Another factor that can be used to differentiate between the two is the Flexibility of the use of the production factors. Here a subdivision can be made into special production and universal production. Product-based properties to the connection to the sales market and the market and to the characteristics of the manufactured products. One way of differentiation is to divide the production based on the trigger. differentiate. Here a subdivision can be made into order-oriented and market-oriented production. production can be made. In the case of order-based production, production is based on orders received. In market-oriented production, a production plan is created and processed based on predicted sales forecasts. processed. A distinction can also be made based on the degree of specification of the product. of the product. In most cases, a differentiation is made here between customer-oriented production and standard production. The two productions differ mainly in that customer-oriented production is more order-oriented production is more order-oriented and standard production is more market-oriented. Process-related properties refer to the differentiation regarding the organization of the manufacturing process or the process of the input factors also leads to numerous criteria that should be taken into should be considered for the classification of the production. The most important distinction is the subdivision of manufacturing in organization types. These organizational types of manufacturing vary in the partial arrangement of the resources, which are dependent on the kind of the products (Kistner and Steven 2001).

3. Theoretical basics of sequencing problems

In the following section, the theoretical basics of sequence planning are explained. First, a basic overview of the sequence planning is provided and afterward, the mathematical basic models are presented. Through these models, it became clear that there are several approaches to solving the problems of sequencing. Sequencing, or scheduling, attempts to form a queue using existing capacities and scheduled operations. With the help of various criteria and an objective function, an optimal processing sequence is then created (Schotten 1998). The objectives of sequence planning can be defined differently. The correct and sufficient definition of the objective function is decisive. Furthermore, the available resources for calculation or planning must also be considered when selecting the target function. The result of sequence planning is thus an order sequence in which the orders are to be processed to achieve the defined goal. Sequence planning differs from detailed scheduling in that it does not refer to precise points in time. In detailed scheduling, each sequence schedule would be assigned a planned start and completion date to the minute. In practice, however, this is not very often adhered to. In companies with sufficient capacities, the use of detailed scheduling is very often dispensed with, as the achievement of objectives is also given with sequence planning (Kistner and Steven 2001). The order is determined by the specification of the order. There are two cases here. In job shop production, the machine sequence is different for each order. In contrast to this, in flow shop production, the machine sequence is the same for all orders (Kistner and Steven 2001).

One of the most pressing issues in production management is flow shop scheduling (Błażewicz 2001). When we talk about flow-shop scheduling, we got several n given jobs and a number of m machines. All these jobs got the same processing operation order through the machines. Between different jobs are no precedence constraints. When an operation is started, it cannot be interrupted and for each machine, it is only possible to do one operation at a time. The goal is to find task sequences on the machines that minimize the makespan. It is possible to choose another objective function like the mean flow time or the total tardiness (Gowrishankar et al. 2001). The flow shop scheduling problem is categorized as NP-complete. Thus, are usually solved by heuristic methods or approximations (Gupta and Chauhan 2015). In the following paragraphs are some of this shortly described.

3.1 Johnson algorithm

Johnson's algorithm (JA) is possibly the most well-known scheduling algorithm. To reduce the makespan in polynomial time, JA provides the best solution to the two-machine flow shop (Allaoui and Artiba 2009). In 1953, Johnson was concerned with finding an optimization for production with two or 3 stations. His goal was to reduce the cycle time of production. His algorithm is aimed at an indefinite number of orders that are to be processed on two machines in succession. The requirements of his process are:

- Each product must be processed first at workstation 1, then at workstation 2
- Only one product can be processed on each workstation at the same time
- The order and processing time per machine was summarized into a number

The algorithm works as follows:

- Create a list with the individual times per machine
- Find the shortest machining time for machines 1 and 2
- The order with the shortest machining time on machine 1, is placed at the front.
- The order with the shortest machining time on machine 2 is placed at the end of the list

Now the two orders are chopped off and the procedure starts again in step 2. If two machining times are the same, the job with the smaller index is preferred (Johnson 1954).

3.2 Simulated annealing (SA)

An artificial intelligence approach based on the behavior of cooling metal is known as a SA algorithm. It can be used to solve issues involving combinatorial optimization that are difficult or impossible to solve. The SA process is presented as a model-free optimization method for NP-Hard problems. SA is a random search method that is modeled by the physical annealing of materials (Osman and Potts 1989).

3.3 Genetic algorithm (GA)

Genetics is a word used in biology. A good parent's genes create superior kids biologically. The creation of Genetic Algorithms is based on the same premise. Genetic algorithms use a population of structures to search a problem space and choose structures for further search depending on their performance. In the context of optimization problems, each structure decodes to produce a point in the problem space. High-performance structures (parents) are subjected to genetic operators to create possibly suitable new structures (offspring). As a result, excellent performers are passed down from generation to generation (Chen et al. 1995).

4. Systematic literature analysis on sequencing problems in flow shop production systems

To investigate the state-of-the-art literature regarding sequencing problems in flow shop production systems the authors conduct a systematic literature review in Scopus as the main source for the search process because it was identified as the most relevant database for scientific publications in the areas of engineering and management sciences. In the SLR, the authors focused on "flow shop scheduling" or "flow shop scheduling problem" which have already been tested in an empirical environment by using the keywords "case study" or "implementation" since 2016, in the English language, and by focusing on articles, conference proceedings, book chapters as a document type in the areas of economics, management, and engineering (Woschank et al. 2020).

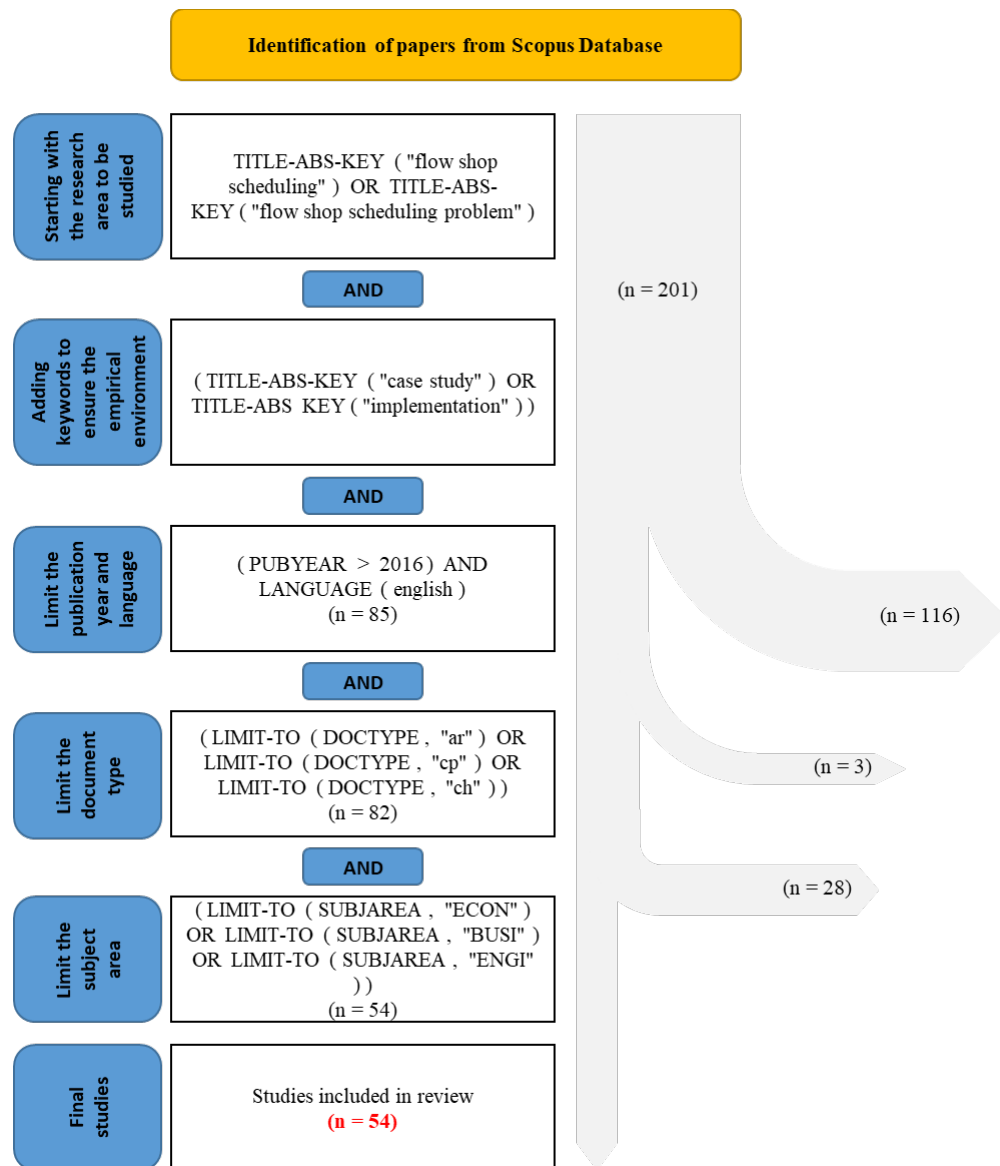


Figure 1. Modified paper selection process based on the search string according to PRISMA (Miklautsch and Woschank (2022), Page et al. (2021), vom Brocke et al. (2009))

Therefore, the search string was formulated as follows: (TITLE-ABS-KEY ("flow shop scheduling") OR TITLE-ABS-KEY ("flow shop scheduling problem")) AND (TITLE-ABS-KEY ("case study") OR TITLE-ABS KEY ("implementation")) AND (PUBYEAR > 2016) AND LANGUAGE(english) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ch")) AND (LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "ENGI")).

Figure 1 is a visual representation of the changing amount of examined papers depending on the added constraints.

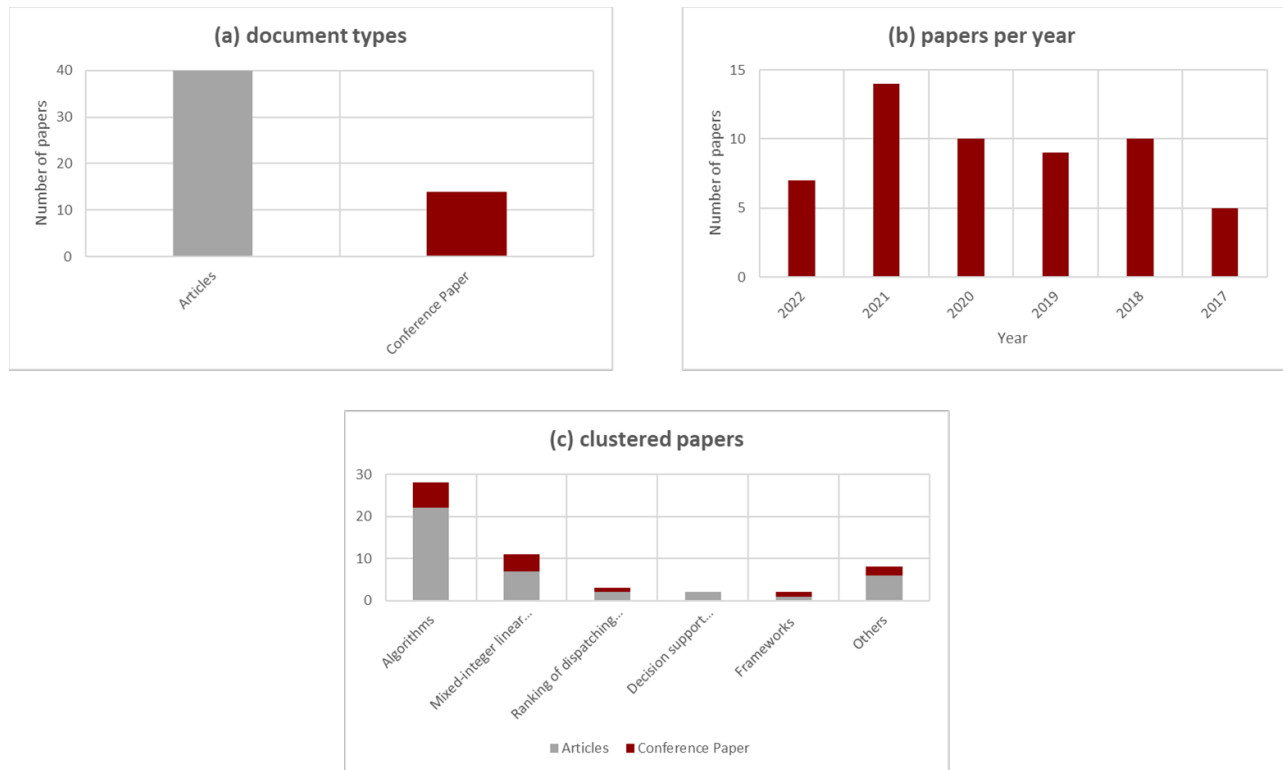


Figure 2. Descriptive analysis of the included papers

Figure 2 describes the systematic literature search in more detail. In (a) the division between Articles and Conference Papers can be seen. The number of papers published in one year is shown in (b). (c) restores the relationship between the clustering in Table 1 and the different document types from (a). Table 1 presents the results of the SLR, leading 54 papers in the clusters “algorithms”, “mixed-integer linear programming models”, “ranking of dispatching rules”, “decision support systems”, “frameworks” and “others”. Several publications overlap in some topics and therefore may fall into several clusters. Nevertheless, they were then assigned according to their main classification.

Table 1: Clustering of the papers based on the SLR

Number	Cluster	Number of publications
1	Algorithms	28
2	Mixed-integer linear programming models	11
4	Ranking of dispatching rules	3
5	Decision support systems	2
6	Frameworks	2
7	Others	8

5.1. New algorithms

In 25 publications, the focus is on the evaluation of existing algorithms or the development of new algorithms for specific tasks. The focus is very often on the improvement of material and energy consumption. The publication of Ramezani et al. (2019) is additionally focused on minimizing makespan as a measure of service level and also the minimization of the total energy consumption.

5.2 Mixed integer linear programming models

The second-largest cluster in our study has been involved in the creation of mixed-integer linear programming models. For some other publications such models were also made, but they are not included here, because the focus in these publications was on a different topic. The study of Fathollahi-Fard et al. (2021) aims aside the minimization of the total energy consumption which is related to production, also on maximizing the social factors like lost working days and job consumption.

5.3 Ranking of dispatching rules

In three of the 54 papers, dispatching rules are used in an attempt to meet various production requirements. Rolf et al. (2020) use a genetic algorithm to solve a hybrid flow shop scheduling problem by predefined dispatching rules at different points. They also show the difference between using a genetic algorithm to assign the dispatching rules and applying standard dispatching rules at the start.

5.4 Decision support systems

Ünal et al. (2020) developed an integer programming model for hybrid flow shops. Their model can be used in a variety of production systems that are organized as hybrid flow shops. Based on their proposed optimization model, they create a decision support system. Kong et al. (2020) guide their case study for sustainable production of hybrid flow-shop scheduling.

5.5 Frameworks

Nahhas et al. (2021) propose an adaptive scheduling framework. They want to address scheduling problems by taking multi-objective optimality measures into account. The main goal of the proposed concept is to find a good balance between the quality of suggested solutions for a problem and the computational effort required to obtain them.

5.6 Others

All other categories summarized here contain only topics that appear once in the selected papers. This category includes, among others, the paper by Azab et al. (2021) which is about a machine-learning-assisted simulation approach.

6. Conclusion

The constantly increasing market pressure requires companies to constantly change and adapt to the market. Due to the changes that occur, good production planning and control is necessary. In-house production planning and control form a part of production planning and control. A subarea of this is, in turn, sequence planning. Sequence planning determines the sequence in which orders are processed. It can also serve as the basis for detailed scheduling. This paper investigated sequencing problems in flow shop production systems. In this context, Johnson algorithm, simulated annealing (SA), and genetic algorithm (GA) were determined as the basic models. Moreover, by conducting a systematic literature review the authors identified a total of 54 state-of-the-art papers which were assigned to seven clusters, namely “algorithms”, “mixed-integer linear programming models”, “ranking of dispatching rules”, “decision support systems”, “frameworks,” and “others”. Nowadays, research is mainly concerned with heuristic methods since the results of these are often sufficient. Moreover, the increasing work performances of computer systems make the calculation of the different possibilities easier and faster. From an economic point of view, it is recommended to use priority rules for the first implementation phase if sequencing has not been done yet. If initial approaches are already available, it is recommended to deal with heuristics. There are different approaches, which are more recommendable depending on the objective are more recommendable. The research is already in a very good way with the heuristic procedures. This should be further explored in the future to make it easier for companies to use the algorithms and approaches they have designed.

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