SEQUENCING OF ORDERS IN MULTIVERSION PRODUCTION SYSTEM

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Abstract

The article discusses the basic characteristics of multiversion production and also presents the problem of production of different product versions on the same production line. The car production is selected as an example of the multiversion production process. Three main branches of the production plant (the body shop, the paint shop and the assembly line) are characterized. Based on exemplary manufacturing process, it is presented, how determining proper sequence of tasks, carried out in the production system, may affect production optimization. This paper presents a problem of sequencing cars, known from the literature as the Car Sequencing Problem (CSP). It also presents the range of reduction of the CSP problem relative to the problem, which occurs on a real production line. For comparison, the structure of an exemplary industrial plant is shown. Based on the presented scheme of the cars production, the importance of use of the buffer warehouses in selected production system is highlighted. Thus, it is given the suggestion to reformulate the CSP issue. In the final part of the article, a sample method of optimization of analyzed production process, focused exclusively on paint shop, is given. This method aims to provide a minimum number of changeovers of robots painting car bodies, which, by minimizing setup times, increases the number of produced cars. It also has an impact on minimizing consumption of paint and solvent used to clean the nozzles of robots whenever a changeover occurs.

Keywords: Multiversion production, tasks sequencing, buffer warehouses, optimization of production

1. INTRODUCTION

Current society is characterized by a high degree of development, which translates into a level of material needs. A tendency to resign from the standard and clichéd solutions for more specific and sophisticated products can be observed. It leads in turn to increased demands for both quality of provided services and delivery time. Individualized customer's needs and the growing demand for different variants of the same product impose on a company the necessity of products differentiation [1]. Unpredictability of orders made by clients, makes today a move away from the Make To Stock production (MTS) to Make To Order production (MTO). It is aimed at minimizing the time between order and delivery of the final product to the customer [2]. For a company, this enforces the need to adjust the individual machines, devices and robots included in the production line for a multiversion production. This requires not only the flexibility of the production system, which should be taken into account in a design phase of the system [3, 4, 5], but also an efficient management and production control system [6]. Thus, on the same production line it is possible to produce different versions of the product, tailored to the customer demands. In modern production systems a variety of products (assortment) or different varieties of the same product (versions) are manufactured. Those production systems are known as mixed-model production systems.

Often used example of multiversion production is car production. On production lines several different vehicle models are usually manufactured and, for each model, different versions can be distinguished, for example in terms of color or additional accessories. As part of this article the stages of a car production will be presented, with an indication of the problems occurring at these stages. In addition, it will be discussed the issue of cars sequencing (the Car Sequencing Problem, CSP) as an example of illustrating the problems of appropriate organization and production planning.

2. CHARACTERISTICS OF MULTIVERSION PRODUCTION

The mixed-model systems are the result of evolution of systems adapted to produce only one product (a single-model production system). In 1913, Henry Ford, founder and then president of Ford Motor Company, as first used in his factory in Highland Park, in Michigan, linear assembly line, which was an absolute revolution in attitude to the mass production. The approach proposed by Henry Ford reduced the price of the model T in 10 years from about 900$ to 290$. Thus, the industrialists' interest in mixed-model systems has increased significantly. Manufacturing of products for daily use, ranging from shoes to furniture and even food, was carried out on a massive scale, so goods so far considered as luxury, have became widely available products, also for less affluent sections of society. And to this day the mixed-model systems are widely used and constantly developed, especially due to their ergonomics, versatility and flexibility. Among the benefits that provide these systems, from the point of view of manufacturers, there can be distinguished [7]:

- ensuring the regularity and continuity of production process,
- elimination of bottlenecks and downtimes,
- full quality control assurance at each stage of production,
- shortening the manufacturing cycle time,
- efficiency increase,
- optimization of communication between the branches of the production system,
- ease of using the system,
- relatively low production costs,
- safety improving at work,
- ergonomics of the environment.

A characteristic feature of the mixed-model systems is a constant flow of materials, to ensure in assumed cycle time, enough time to complete all the operations resulting from the production plan as well as the high level of workstations utilization. It is achieved by assembly line balancing and sequencing of production orders. In the case of MTS production sequencing of orders can be carried out at the beginning of a production process. However, in the case of MTO production it is necessary to ensure the possibility to change the sequence of orders in a course of the process, simultaneously maintaining the continuity of production. It is possible through the use of buffer warehouses between workstations. This solution has been used in the production of cars.

3. THE CAR MANUFACTURING PROCESS AS AN EXAMPLE OF MULTIVERSION PRODUCTION

Production of cars consists of several steps that are following each other according to a specific order - sequentially. Although the models of vehicles, that are currently produced on the line, are similar to each other, it is possible to distinguish some features, that are characteristic for the particular types of a given car model. Customer buying a vehicle can determine not only the color of this car, but also many elements of equipment, for example: a sunroof, air conditioning, embedded navigation and others. This indicates that production of cars can be classified as a multiversion production.

In the initial phase of cars production, in the body shop, robots and operators are welding the various parts of the vehicles to form right structure of a car. Then the connected parts are sent to a paint shop, where they are painted by robots equipped with spray guns. Therefore, at their way out from the body shop, cars should be arranged in a specific order, depending on color which they will be painted on. In the last phase, in the assembly line, various components are added to the vehicles, adequately to the selected options [8]. A different number of additional components may characterize each configuration.

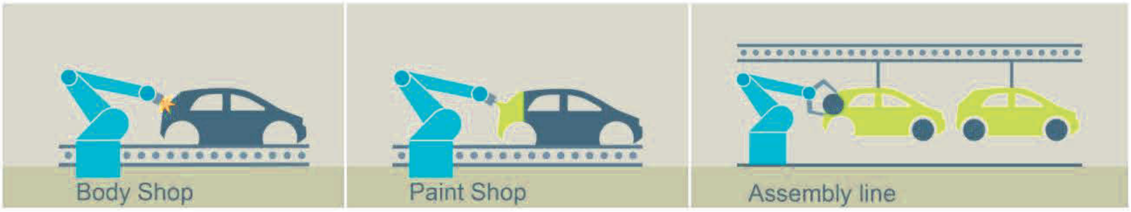

Figure 1 Stages of the production line [9]

In the following sections there are presented characteristics of two plant shops of car production line: the paint shop and the assembly line, from a perspective of the constraints which affect sequencing vehicles along each part of the line.

3.1. Paint shop

The paint shop is equipped with robot stations, which are retooled every time the color changes. The capacity of a production line for the paint shop depends not only on the number of the cleaning guns for each change of color, but also on a periodic cleaning of paint guns. Two examples of color sequences, presented in **Figure 2**, show the effect of cars alignment with the frequency of the cleaning guns. It is assumed that along the line there is located only one robot and its gun is cleaned periodically every three cars. As can be seen, in both cases, the nozzle should be cleaned at the beginning of the next production day, because of the planned change of color. In addition, in the first case (**Figure 2** - SEQUENCE A) it is necessary to clean the gun twice - the first time due to the periodic cleaning, the second time due to change of color. However, in the second case there is only one cleaning included both periodic cleaning and cleaning due to a color change. This example illustrates the importance of proper planning of car sequences on the line. The appropriate sequence of cars plays an important role in a production optimization [8, 10,11].

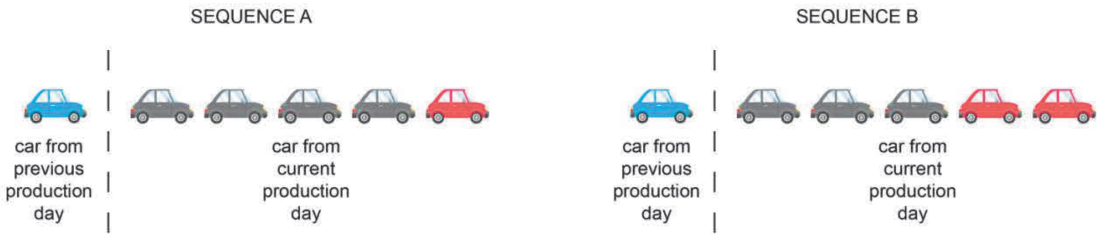

Figure 2 Sample color changes for the second type of paint [9]

Both cleaning of spray guns and retooling cause delays, which sum is the greater the more often robots are retooled. As a result, periodic cleanings and color changes increase not only the consumption of a solvent, but also the consumption of paint. During flushing of spray guns, some paint, which remains in the nozzle and on the walls, will not be used, because of its removal during the cleaning process. It proves that the consumption of paint increases. A similar situation takes place when the periodic washing of nozzle will not be taken into account during the sequencing of cars, as shown in **Figure 2** (SEQUENCE A).

Therefore the aim of the paint shop is to minimize the number of color changes (the number of necessary cleanings), allowing to reduce both costs and production time [8, 10, 11].

3.2. Body shop and assembly line

In the body shop and the assembly line there is a problem of an appropriate arrangement of car sequence. It is related to a produced type of a car model - the vehicle can be three- or five-door and the decision about it is made in the body shop. The car can be also equipped with additional components which are installed in the assembly line [10].

Therefore the aim of the body shop and the assembly line is to smooth a workload along a line by balancing an effort in different working stations [8]. Balancing of the assembly line is achieved through distribution of operations between workstations, so that idle time is minimal [9]. From the perspective of the Car Sequencing Problem, balancing of the assembly line means an even distribution of a workload along the car production line, which requires extra assembling operations (installing additional components). It allows avoiding overload of the station in assembly line [8].

4. THE CAR SEQUENCING PROBLEM

The sequencing can be regarded as a short-term decision-making process. The aim of sequencing is to define the order, in which the different variants of products will be carried out. This sequence should be determined in such a way, that the demand for all products planned in the Master Production Schedule (MPS) has been met. The sequencing problem arises for example in the multiversion production of automobiles or bicycles, because there are many variants of products. The sequencing of production variants smoothes the load of the production system (which is most commonly used on the assembly line) by mixing the order, in which the products will be manufactured. Such an approach allows for maintenance of stability and for work standardization. The sequencing enables carrying out the production in order of customer orders. It is easier to optimize the operation of the system designed to multiversion production, when the workstations are multifunctional and work in several variants of production. The planning of sequences of product variants provides greater flexibility in the production process.

As has been mentioned earlier, production of cars can be classified as a multiversion production. This implies the requirement to plan an appropriate sequence of cars on the production line to optimize production, both in terms of costs and time needed for machines and robots retooling or in terms of productivity [10]. This problem has been defined in the literature as the Car Sequencing Problem (CSP). It has been shown that this problem belongs to the NP-hard problems, so there are not any known algorithms that solve the problem in a polynomial time [12, 13].

The Car Sequencing Problem was first introduced in 1986 by Parello [14] and a formulation of this problem was slightly different from modern understanding of the CSP problem. The issue described by Parello concerned scheduling a set of vehicles on the assembly line to meet imposed assumptions about the throughput of the line. In 2005 the French Society of Operations Research and Decision Analysis organized a ROADEF Challenge 2005 with the Car Sequencing Problem as a subject. The organizers required to take into account not only capacity constraints imposed by the assembly line, but also paint batching constraints (the paint shop) and two categories of capacity constraints - high and low priority constraints. Thereby to solve the CSP problem proposed by Renault it had to include all three plant shops (**Figure 1**): the body shop, the paint shop and the assembly line [8], but this problem omits the existence of a buffer warehouse between stages and inside individual shops and lines. However, this buffers occur in the actual production lines, so it is important to take this into account in the search for a solution of the real CSP problem, because buffer warehouses play an important role in the planning of production and in the sequencing of production orders.

5. BUFFER WAREHOUSES IN CAR PRODUCTION SYSTEM

The buffer warehouses are elements of production processes, often used to ensure continuity of a production. They could occur in the form of physical devices and their main purpose is to store components, spare parts, tools and many others. These devices are widely used, for example in: production lines, distribution centers, wholesaler's and can also be used for archiving documents in the office [9].

From the point of view of orders sequencing the most important buffer warehouses in car production are parallel buffers (**Figure 3**).

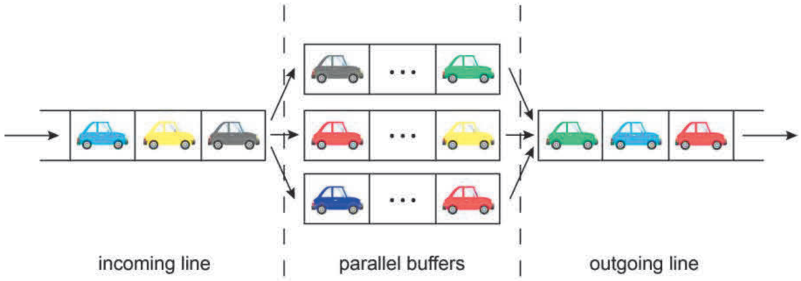

Figure 3 Production line with parallel buffers strategy [9]

When a structure with parallel buffers (**Figure 3**) is used, the decision of locating the vehicle on a buffer line is taken at the end of the incoming line. In turn, the outgoing line is successively filled with cars taken from the parallel buffer line, according to defined priority, for example FIFO strategy (*First In - First Out*).

This type of buffer is mainly used in the paint shop (**Figure 4**). Usually, buffers occurring before and after the paint shop are also qualified as buffers and are so-called the Body Distribution Centers (BDC). The sequencing of orders in the "input" BDC is carried out due to optimization aims of the paint shop, while the sequence of cars in the "output" BDC is adapted to requirements of the assembly line.

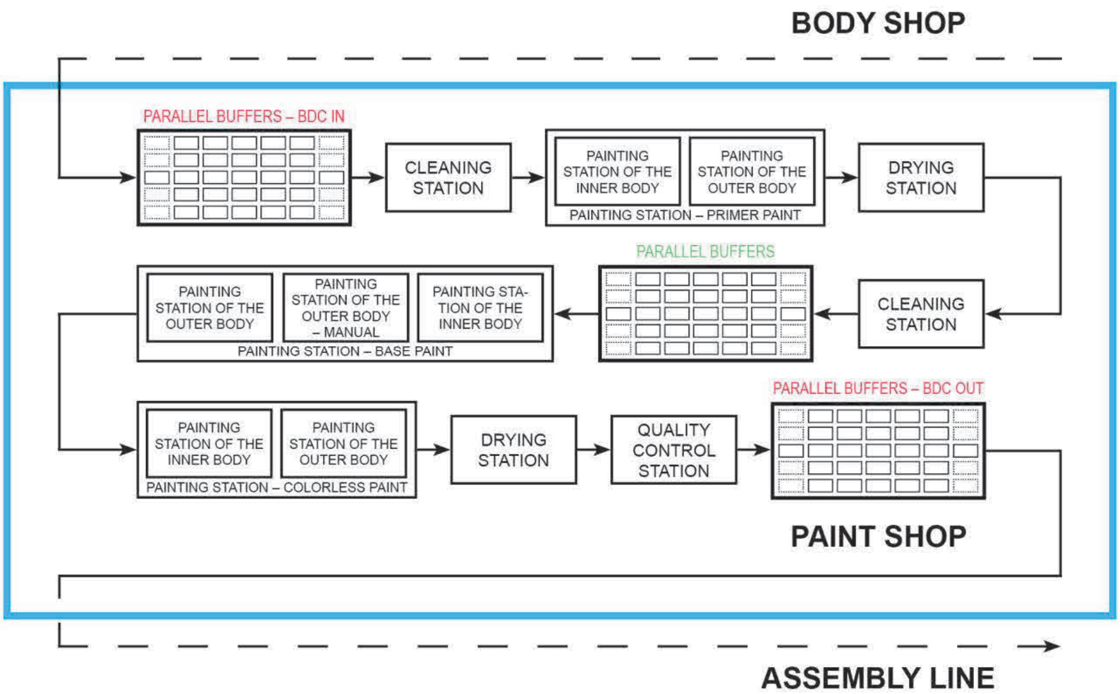

Figure 4 Structure of the paint shop

6. THE SAMPLE APPROACH TO THE CAR SEQUENCING PROBLEM

One of the applied and relatively simple solution of the Car Sequencing Problem is the approach based on historical data and probability issues. However, this solution is dedicated exclusively for the deployment of the bodies in the first buffer warehouses (BDC in). The approach is to determine, what is the probability that a body will be painted on one of the available colors. For this purpose a so called bank of colors and bank of bodies are created. The bank of colors includes all available colors. The bank of bodies provides the information, how many bodies, from the available recourses produced within the last n jobs, are painted on particular color. Then for every color the obtained probability is assigned and the bodies, which will be painted on the color with the highest probability receive the highest priority. Thus, those bodies are so disposed in buffer warehouse, that they as the first left the buffer. The discussed approach is noteworthy because of its simplicity. However, this solution does not include the sequencing of the cars in other buffers and does not take into account the problems of assembly line optimization, what is directly related to the buffer BDC out.

7. CONCLUSION

In conclusion, the use of the mixed-model systems in industry allows a production of products in different versions, tailored to customer needs and relevant to personalized orders. Definitely it increases the company's competitiveness on the market. The appropriate management of the production process and ensuring maximum utilization of workstations among others things through proper production plan are important. Unfortunately, due to the unpredictability of orders, production plan should be verified on an ongoing basis. In order to ensure the continuity of production, the mixed-model systems are equipped with buffers, allowing changing the sequence of orders. This issue is classified as a NP-hard problem, hence the research for the solution of this problem is still conducted. The example of approach to the problem of orders sequencing was presented in this article, however it is only the basis for the future discussion.

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