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Improving the Production Efficiency Based on Algorithmization of the Planning Process

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Abstract: Planning and managing the production process are key challenges faced by every manufacturing organization. The main contribution of this article lies in the analysis and design of a planning algorithm that takes into consideration the specifics of this environment. The proposed algorithm encompasses elements of batch production, including a just-in-time approach. The article focuses on scenarios within batch production. Managers of manufacturing and supply companies must ensure smooth fulfillment and uninterrupted production of the agreed-upon quantity of parts. However, this task presents complex challenges. The product portfolio requires meticulous sequencing of production batches, and subsequent parts need to be temporarily stored in their raw state for further processing. Moreover, product variability necessitates frequent adjustments to the production line, resulting in delays. Shortages in manpower additionally place demands on shift organization. The company's primary objective is to increase production efficiency while simultaneously reducing inventory and minimizing non-standard shift work. The challenge was to reconcile seemingly conflicting company requirements and to concentrate on solutions with swift implementation and minimal costs. Ensuring seamless production operation can be addressed by expanding supporting technologies or by increasing production capacity, such as acquiring an additional production line. However, these options entail costs and do not align with the company's expectation for immediate impact and cost savings. However, improving production efficiency can also be achieved by altering the approach to production planning, which is the central theme of this article. The key element is ensuring that the customer plan is adhered to while working with a fixed production logic and variable input factors that must account for various non-standard situations.

Keywords: production optimization; algorithm; management; automotive production

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1. Introduction

In connection with the rising standard of living in the last decade, the automotive industry has become a very competitive environment with extremely rapid technological development. Vehicle manufacturers cooperate with suppliers that produce parts for them. Both vehicle manufacturers and customers are placing ever-increasing demands on the quantity, quality, and flawless appearance of products [1]. Production management is an activity that involves monitoring and managing production processes concerning manpower, capacity constraints, and material availability so that the required quantity and quality of products are achieved in the required time [2]. An important component of production management is its planning. Planning is used to make optimal use of equipment and machinery, human resources, production processes, and the purchase of materials [3]. The basic benefits of controlled and planned production include—higher production capacity, smoother flow of processes and materials, reduction of money stored in stocks due to lower safety stocks, optimized use of machines/workplaces/employees, elimination of time losses, and more stable product deliveries. Productivity is a key factor in a company's production performance. Frequent adjustments to production plans lead to increased costs, reduced productivity, and also a lower level of customer service [4]. Assuming that a supplier cannot invest heavily in productivity by purchasing expensive production equipment, productivity can only be increased by improving production planning and permanently reducing stocks of already manufactured products to prevent damage [5].

In the realm of production optimization, particularly within the automotive industry, this article delves into the critical pursuit of enhancing production planning to bolster overall productivity. It zeroes in on a scenario frequently encountered in the industry—where a production and supplier company engaged in series production crafts partial products for their customer, typically a car manufacturer. The crux lies in the seamless provision of these parts to the customer's production process, with an imperative for consistent and agreed-upon daily deliveries. Within the framework of a production and supply company, production planning takes on a complex complexion. It necessitates meticulous consideration of multifaceted factors, ranging from meeting the stipulated delivery volumes to orchestrating reconstructions of the production line for a diverse product portfolio. The overarching objectives encompass mitigating production losses, curbing product storage, and minimizing overtime demands. A pivotal avenue for achieving heightened productivity rests in the investment in production facilities or a strategic reorientation of the production planning methodology. The article squarely revolves around a transformative shift—the augmentation of productivity achieved through the algorithmization of the planning process. The bedrock of this discourse is the creation of a planning algorithm tailored for mass production schemes. Unveiling the blueprint, the article expounds upon the algorithm's underlying principles, its benefits, and its potential applications. With its foundations tested in the real-world dynamics of a live company, the algorithm then underwent a process of generalization to adapt to broader settings of series production. The article further explores avenues for algorithmic expansion, anticipating a wider spectrum of functionalities.

2. Theoretical Background

Most products in the automotive industry flow through a pipeline, which begins with the subcontractor and follows the transport process to the customer's production line. Most companies manage these two functions independently, with little or no coordination between production planning and distribution planning. This separate approach works in cases where there is a sufficient amount of demanded products in stock in the buffer. However, this approach does not coincide with the currently solved problem, where the goods are taken away in the form of Just-In-Time and the management of the supplier company tries to minimize the warehouse [6]. The demand for enterprise resource planning systems, which can solve these requirements with the help of information systems, derives from this trend. This would achieve full traceability of all manufactured and stored pieces during all activities that affect the price of delivered commodities. At the same time, there is a demand to calculate the value of various resources of the company at any time on demand, not only at certain time intervals, as is currently the case. On the other hand, manufacturing companies are constantly looking for effective strategies for optimizing individual sub-operations. Many approaches are used in this search. The core of all business process reengineering activities usually consists of already well-known frameworks [7]. In this context, manufacturing companies need a production planning system that can ensure a balance between satisfying customer needs and the efficient use of production resources. To achieve this during the Fourth Industrial Revolution, data must be collected and stored as part of the entire production process in real-time. This requires efficient data communication, which will be based on integration and interoperability with other systems. Even though the requirements for a new method of production planning are clearly defined, recent research has shown that manual solutions and ERP are still the basic principles on which most planning departments within manufacturing companies operate. However, this has long resulted in multiple problems. From a technical point of view, these solutions do not provide data interoperability, the evaluation of the output of these solutions is limited, and they are very time-consuming is no retrospective evaluation of bad solutions. From a practical point of view, these solutions do not respect all system variables and limitations, the use of resources and capacity is not balanced in the long run and there is a high risk of stock shortages [8].

With a few exceptions, the analysis of industrial production is traditionally researched and offered as a commercial service by various companies, but they provide different data formats in different time derivatives and each who offers these services has a different approach to solving these problems. In general, however, all of these procedures begin with a preliminary analysis of anomalies in production reports, data, and errors, so that the calculation of global measures follows various internal protocols, which are often the intellectual property of these service providers. Of course, there are often significant differences in the method and results of analysis, but they do not matter to users if they are familiar with the definition [9].

Standardization of individual operations allows manufacturing companies to eliminate work without added value by reducing complexity and unnecessary redundancy. Companies use process standardization to achieve transparency and uniformity of operations across the value chain. In turn, standardization is considered an organizational effort to bring operations into a single standard business process [10]. Operations that have been standardized effectively reduce the deviations associated with each task, minimize ambiguity, and help production staff avoid costly errors. The unification of these processes ensures the high quality of the services provided [11].

However, in [12] found that standardization to an excessive extent can lead to errors and breaches of work safety. In contrast, [10] define standardization as part of the "meta" process of continuous improvement in an organization. However, the principle of standardization, thus the permanent integration of the successfully evaluated changes into the process, is the principle of most improvement methods [13]. The process is based on the concept of continuous improvement, ensuring communication and information flow between the teams and the individuals who are involved in specific projects to improve production processes. This is part of the Six Sigma DMAIC cycle (Define–Measure–Analyze–Improve–Control), which is crucial for the Control phase, where newly introduced processes are gradually documented, the staff is trained, and outputs monitoring plans are set. The aim is to accept the new process as a recognized standard and the basis of generally widespread production [14]. Lean is a set of tools that are important for the identification and subsequent permanent disposal of waste. With the increasing elimination of waste, the quality of production is improving, while production costs and time are constantly decreasing. Typical examples of these tools are 5S, Kanban, and Poke-Yoke. Lean production also focuses on improving production flow, from which the flow of work directly derives, while permanently eliminating inequality through the system. Techniques that address process flow include balancing production in the presence of Kanban [15]. Article [16] deals with the theoretical and practical implementation of preventive maintenance based on a unique modification of the total productive maintenance (TPM) methodology. The innovative approach of preventive maintenance management was implemented in the real production hall of ITT (Czech Republic) and has been verified. Methodology TPM (Total Productive Maintenance) is a managerial and technical approach to maintenance and equipment management in a manufacturing environment. The goal of the TPM methodology is to maximize the performance of equipment, minimize breakdowns, losses, and failures, thus improving overall production efficiency. TPM focuses on involving the entire team, including operators, maintenance personnel, and managers, in the equipment maintenance process to achieve high levels of reliability, availability, and machine performance. The TPM methodology is based on several key principles and pillars. Overall, TPM aims to achieve the highest reliability and performance of equipment, which ultimately contributes to the overall efficiency of the manufacturing process. More details of Industry 4.0 and TPM problems are described in [17,18]. The TPM methodology is widely used in practice as evidenced by the following publications [19–24].

Each of the above works operate with the classic TPM methodology, but our approach has adjusted the individual parameters of the methodology and completely new ones have been delivered, thus creating a unique methodology that can be used in industry. Our algorithm enhances the efficiency of the production process, hence it falls within the scope of TPM (Total Productive Maintenance). Special algorithms like using intelligent expert systems [25] is a necessity for improving the situation of organizations. Since the process of identifying strategy in a strategic plan is time-consuming and costly, the role of expert systems in strategic planning is considerable. An automated planning system introduction at several instrument-making enterprises was presented in [26].

3. Research Methodology

The main structured method used for the research of the planning algorithm, often used in Six Sigma is the DMAIC method and statistical tools that can show opportunities for improvement. Lean Six Sigma contributes significantly to production process improvement, identification, and resolution of a wide range of problems while reducing associated costs, inventory stocks, and operating expenses. The choice of this method was based on its internal structure, which allows the achievement of goals through accurate knowledge of the entire process while avoiding quick conclusions and spending financial and time resources on ineffective actions. In other words, this management method follows the effectiveness of process management through the diagnosis of undesirable situations and the consequent search for solutions. The main objective of DMAIC is to control and improve processes, services, and products continuously, with a beginning, middle, and end, while bringing an important aspect not only the solutions of different kinds to problems but also the issue of sustaining the proposed work [27].

For a better understanding of the production process and measuring of important values, which are related to designing of production planning algorithm, the was important to make structured interviews with production operators and production management. It is a qualitative research method, where this approach aims to ensure that each used interview is presented with the same questions in the same order. This approach ensures, that answers can be reliably aggregated and that comparisons can be made with confidence between different survey periods and sample sub-groups. Data should be collected by an interviewer rather than through a questionnaire, the choice of answers to questions is fixed in advance, through open-ended questions can also be included within a structured interview [28].

The solution of the task is often formulated so that the sequence of the tasks remains not quite clear. Therefore, it is necessary to determine the exact rules applicable to the sequence of the partial operations. This process is called algorithmization of the tasks of the production processes. To solve the individual mass production processes, we need to find an algorithm, i.e., to find a unified sequence of actions, which are to be performed to find, at the end of a finite number of steps, the solution sought after to the tasks, which are related to the production process. It's also required to be aware of the problems, that cannot be solved algorithmically. Solving this algorithm means transforming the input data into output ones, following a specific sequence of steps, i.e., in every single moment, only a single step is performed. Both input and output data are defined by input and output characteristics—conditions [29].

4. Research Results

Companies that deal with series production with contracted orders for many years in advance often face similar typical problems. The companies have the know-how to produce a certain product and it allows them to use it for more separate customers, but they face a lack of production capacity to cover customers' deliveries. Also, the transport of imported materials from distant countries can bring difficult situations. The transport can take several weeks and it sometimes happens that a bad batch arrives that does not meet the customer's requirements. Therefore, it is not possible to produce contracted products or reduce productivity on the line. It together with the requirements for the maximum possible reduction of stocks, means that lost productivity can no longer be caught up and therefore deliveries to the customer will not be satisfied. In such a case, it sets the situation, which means stopping the customer production line, which results in huge fines and also a loss of credibility in the business field.

However, there are two ways to deal with this situation. The first option is to order additional production lines that will produce products for another customer, which solves only the first problem and only partially. Re-ordering a new production line in a corporate environment means several months of analysis, negotiation, design, and approval at the company's headquarters, where they may eventually reject this option for many reasons, often due to high input costs. Industry 4.0 often means multi-million investments and more time spent designing and creating this device. This means that the result can be seen on the horizon of 1–2 years, and the profit will not be brought immediately.

The second option is the content of this research; it seeks to achieve improvements through a change in the production planning process. The system approach to the planning process should be achieved by its algorithmization.

The planning algorithm development has expectations as follows:

- The planning algorithm will improve production efficiency using minimal costs.
- The algorithm will respond to dynamic inputs, and a production plan will be generated so that the warehouses remain permanently at a low level and only what is needed at a given time is produced.
- The approach will bring standardization to the production process, which will have a direct impact on the cost savings associated with storage, and this also reduces secondary costs, when there will be no need to stamp out pieces that are obsolete or damaged by long storage.

The main aim is to design a planning algorithm that can respond to different, dynamically changing inputs, set priorities based on certain criteria, and compile a functional production plan for a whole week to minimize line shutdown, which is a major problem causing a lack of production capacity.

The phases to solve this challenge are as follows:

1. Case study in a real company, basic algorithm development, and its verification.
2. Generalization of the algorithm for use in companies with similar production and planning conditions.
3. Possibilities of further development of the planning algorithm.

4.1. Basic Algorithm Development

To solve this challenge, a case study was processed in a company that falls into the field of automotive. The methods that were used for the study are DMAIC, algorithmization, and structured interviews. As part of the structured interviews, it was necessary to gain awareness of the operation of the production equipment from the perspective of the operator and also from the perspective of production management, which is directly responsible for production efficiency. During interviews with the staff and technology of the production unit, precise data were found and measured, which are directly related to the production of each piece of product, and these data were incorporated directly into the algorithm, as they are related to production capacity. Interviews with production management led to a detailed description of the production process, including material flow, finished pieces, and follow-up activities.

DEFINE: In line with the DMAIC improvement cycle, the baseline situation in the organization was first characterized. The object of interest is the company, which supplies plastic components for the car manufacturer. It is, therefore, a supplier company; whose sole customer is another company. The subject of our interest is the production line, which produces 4 types of products. Production on this device takes place every week in a 5-day cycle. It should not be produced on weekends because the customer company produces only on exceptional weekends and the production capacity of the equipment is sufficient to satisfy the contracted quantities. However, a situation may arise when there is a failure on the line or there is a lack of material, then these contracted supplies cannot be met if the stock is minimal. Another motivation is a new business opportunity to produce products on this line for another customer and it is necessary to ensure production planning sufficiently efficiently, with permanently low stocks. The contracted quantities of delivered pieces are fixed and are known well in advance. Removals take place several times a day in the form of JIT, so it is necessary to always have a certain amount of product available during the day, even for subsequent processes.

MEASURE and ANALYZE: The main reason for the design and creation of the planning algorithm is the current effort to minimize stockpiles due to product obsolescence and their occasional damage, while smoothly meeting customer needs. Due to the permanent shortage of personnel in production, the possibility of overtime shifts in the case of technical problems is considerably limited and the need for overtime shifts can probably be prevented by better production planning. When changing a product whose production has just ended, the production line must be suspended for 120 min, reconfigured and then production can begin. It takes an average of 1 min to produce one piece of product. TP, total time spent on products production, can be expressed (1):

$$TP = \sum_{x=1}^{n} (TMx + QPx * TPx) \tag{1}$$

where TM is time needed line reconfiguration, QP is quantity of product type, TP is time spent on one unit of product type.

The line conversions are the largest consumer of production productivity, as each conversion means 120 pieces of less produced parts, so the goal of the algorithm is to minimize these conversions, but not at the cost of supply endangerment. The number of product types produced has a direct effect on the capacity of the production line. Each type of product requires a time-consuming reconfiguration of the production line, which is the largest loss of production time within a given production day. The capacity of production is calculated (2):

$$PC = \sum_{x=1}^{n} \left(\frac{PTx - n * RecT}{PTx} \right) \tag{2}$$

where PC is production capacity, PT is production time of one day, which should be 1440 min totally, n is number of reconfigurations in given day and RecT is reconfiguration time, which is 120 min.

In addition, after the start of the production line after the reconstruction, a test phase takes place, when pieces that are not of good quality come off the line and it can happen that the first few dozen pieces will be bad. If a defective product leaves the production line, there is a certain chance that the product can still be repaired in the next post-production. Produced pieces that have not yet passed the following process are not registered in the production information system, so the production planner does not know how many produced pieces now are (this gap is called the 'gray information zone').

When designing the planning algorithm, various variants were considered, of which examples of three variants are shown in Figure 1.

The crucial decision for the algorithm is to determine the production plan at the beginning of the production day. More aspects had to be considered when evaluating the variants (see Table 1).

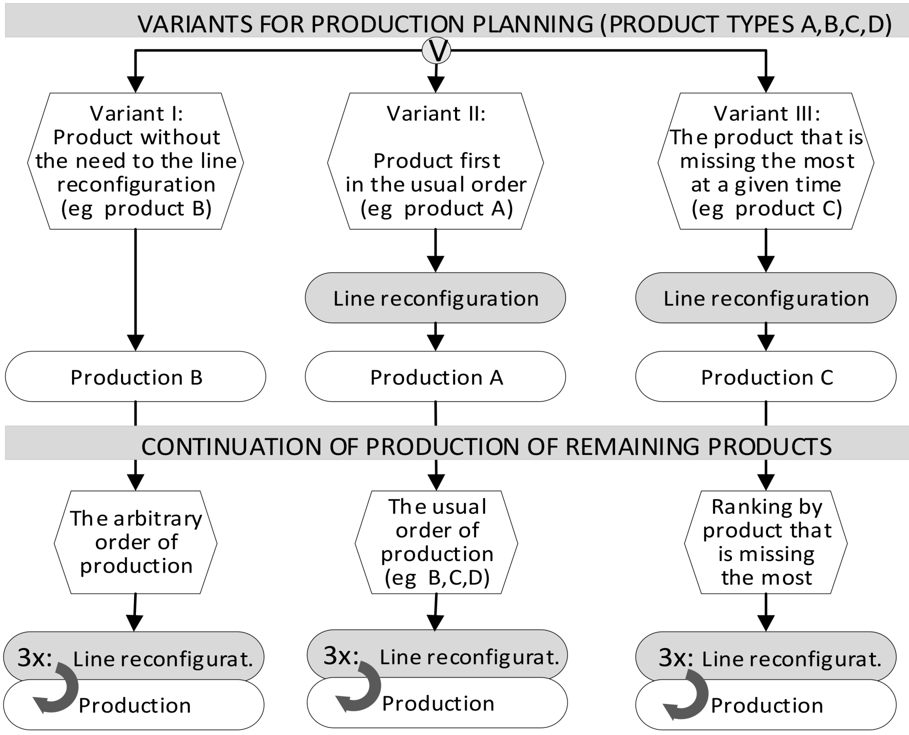

Figure 1. Examples of proposed planning variants.

Table 1. Basic aspects of production planning.

Aspect	Description
necessary morning stocks in the stock	at the beginning of the production day (before the start of production), certain volumes of all products must be available in the stock to ensure additional deliveries of products to the customer;
continuous products delivery	exports of manufactured products are carried out every hour during the entire production shift
most missing quantity of product	this term is related to the continuous delivery of products to the customer during the day, therefore the critical product is determined among the products at the beginning of the production shift, it means the product with the most missing quantity and therefore with the highest production priority
storage zone	the stock contains manufactured products in two categories, one category is finished products intended for transport to the customer, and the other category contains unfinished products that are intended for repair or subsequent modification (post-production);
gray information zone	products are registered in the information system only when they are finished products (including final adjustments); a gap in the register (in other words a gray information zone) arises so that the product is manufactured on the line, but the final adjustments (painting) have not yet been completed, so it is not registered in the information system

At the start of the production day (at 6:00), the contracted customer requirements and the actual quantity in the storage zone are evaluated against each other. Recall that the value of the number of products in the storage zone is skewed due to the gray information zone. The products are delivered to the customer continuously, resp. every hour. Therefore, it is necessary to strengthen the production of those products that are currently missing the most. This means that at the beginning of each production day (at 6:00 a.m.) it is necessary to find out which products are missing for that day, rank them according to the shortage from highest to lowest, and produce them in that order.

Although it may seem that variant I and variant II are better due to the savings of one reconstruction of the production line, in the long run, this is not true. After consultations with the company's management, it turned out that JIT deliveries to the customer take place every hour, and because there is no overview of manufactured pieces that are not registered, it cannot be expected that there are some pieces in this storage zone are needed, therefore only variant III was put into operation.

The proposed algorithm includes the following procedure:

- The most missing product is identified at the beginning of the day (at 6:00). This product has the highest production priority (priority no. 1). This product is then produced in a precisely determined quantity.
- If the missing product has been fully produced, the algorithm will check for other products their missing amounts.
- If nothing else is missing, this product (with priority no. 1) is produced until the end of the production day, which means by 6:00 am the next day.
- If another product is missing (product with priority no. 2), this product can be produced. The algorithm will still check if it can be produced by the end of the day—whether there is enough time. If there is not enough time to produce the entire volume, then the algorithm evaluates the missing unproduced quantity and evaluates a warning alarm, that production capacity is not sufficient to satisfy the customer's plan.

The algorithm was applied within the SW module for production planning. An example of the algorithm part is shown in Figure 2.

```
int main(int argc, char **argv){
const int totTime = 1440;
    const int reconf = 120;
    const int prodTypes = 4;
    const int cycleTime = 1;
    const int startStock[4] = {200,300,400,500};
    const int custPlan[4] = {500,400,800,200};
    int stock[4];
    //compute priorities
    for (size_t i = 0; i < prodTypes; i++){
        diff[i] = startStock[i] - custPlan[i];
    }
    std::sort(diff, diff+prodTypes);
return 0;
}
```

Figure 2. The part of the planning algorithm—production prioritizing.

IMPROVE and CONTROL: Based on the previous analysis, an algorithm was compiled that proposes a production plan for the entire current week according to the agreed logic. There are dynamic inputs at its input, which change with each use—the current stock is used here, the production plan of the customer company, and the current production program, which tells which product is being produced. Due to the findings that the algorithms based on variants I and II could in certain cases critically endanger the supply of JIT parts to the customer, the algorithm based on variant III were chosen, which clearly states that after the end of production of missing parts for the day, production continues until the next day, when the line stops and reconfigures as needed.

After creating the algorithm, a test phase was started, where the solution was tested for a certain period. The recorded results from previous production cycles and the new outputs achieved using the planning algorithm were compared. The result is that thanks to the use of automatic production planning it is possible to save at least 1 production line per week, which means saving at least 2% of production capacity (Table 2). This is a great result, as this saved capacity means the production of ~120 pieces of the product in addition to the previous solution. The graphical representation of the algorithm is in Figure 3.

Table 2. The results of of production capacity.

Parameter	Manual Planning	Automatic Planning	Unit
Count of reconfigurations	23	21	
Time of reconfigurations	2760	2520	minutes
Production time	11,640	11,880	minutes
Count of products made	11,640	11,880	pieces
Number of NOK pieces	61	62	pieces
Line productivity	83	85	%

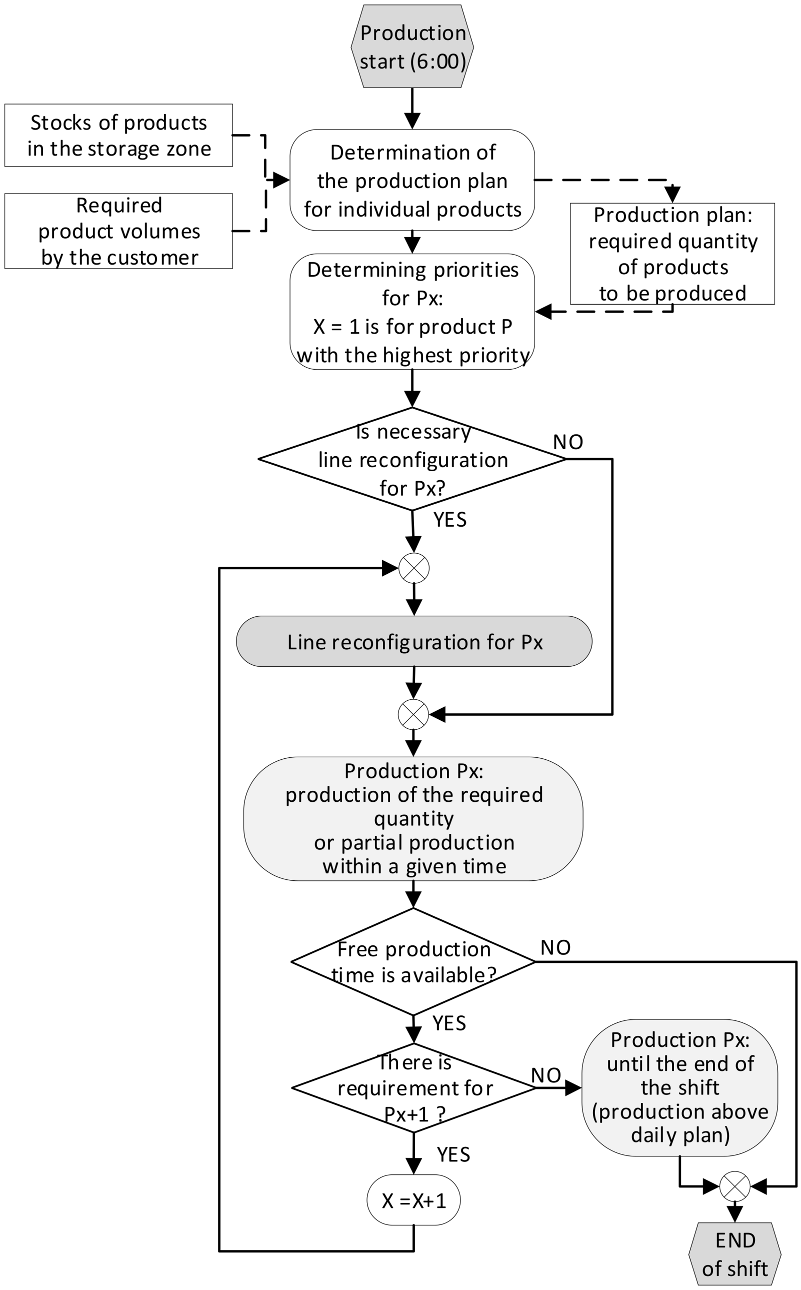

Figure 3. Graphical representation of a general planning algorithm.

4.2. Generalization of the Algorithm for Use in Companies with Similar Production and Planning Conditions

The algorithm is generally written to be applicable to most companies that are engaged in mass production (Figure 3). It is currently designed to take into account handwritten input data that is drawn from the report and therefore does not work in real-time. The usability is for one production line, in the future it is planned to finalize calculations for more lines on which it is possible to produce the same products. Once this functionality is complete, it will be possible to use it in the vast majority of companies that produce on a mass production basis.

4.3. Possibilities of Further Development of the Planning Algorithm

The proposed solution improved production efficiency (Figure 4). The planning algorithm represents a certain initial prototype, which can be further developed. There are specific challenges and general challenges which can be further solved. Specific challenges have been identified for the specific production line where the case study was conducted, general challenges are tied to a generalized planning algorithm. Specific challenges include, for example, the lack of feedback on the production information system or the gray area. The gray zone represents temporarily unregistered products, however, this weakness will be removed with a connection to the information system. This will bring a complete overview of real-time production and additional saved production capacity. General challenges are about extending functionality to users. It can be a development of reports for various company departments, as well as advanced functions for management support in decision-making in risky production situations (failure, lack of material, etc.). For the purchasing department, there can be added functions, that will enable more accurate material planning, thus reducing material stocks. Also, there can be made a module for the maintenance department, which will enable forecasts of line stops for better planning of technical maintenance and engineering changes. The connectivity within the internal information system for faster monitoring of the current production situation seems to be very useful, mainly due to faster response in the event of crises. The proposed planning algorithm represents an increase in production efficiency, almost without financial investment. Of course, further improvements and increases in production productivity can be extended with the application of investments in interconnection with information systems and more detailed product monitoring.

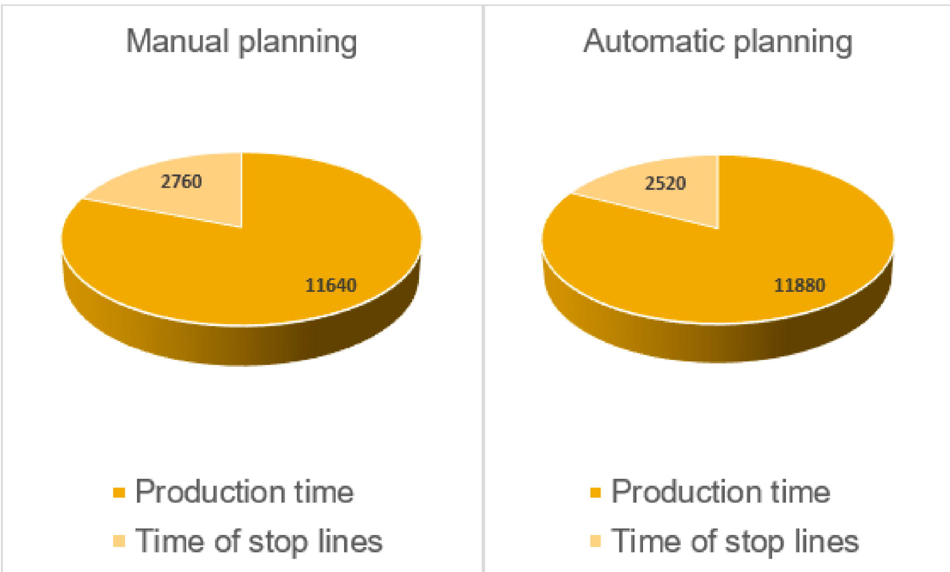

Figure 4. Chart of production time in past two weeks with manual and automatic planning.

5. Conclusions

Improving the efficiency of series production was the basic goal of the research. Increased productivity can be ensured by investing in production facilities or changing the approach to production planning. And it was the change in the planning mechanism, or more precisely its algorithmization (without financial investment), that was to bring about improvement.

The expected benefits were as—the planning algorithm will improve production efficiency using minimal costs; the algorithm will respond to dynamic inputs, and a production plan will be generated so that the warehouses remain permanently at a low level and only what is needed at a given time is produced; the approach will bring standardization to the production process, which will have a direct impact on the cost savings associated with storage, and this also reduces secondary costs. The main aim was to design a planning algorithm that can respond to different, dynamically changing inputs, set priorities based on certain criteria, and compile a functional production plan for a whole week to minimize line shutdown, which is a major problem causing a lack of production capacity.

The procedure was divided into three phases. The first phase consists of a case study in a real company, this phase includes the basic development of the planning algorithm and verification of its functionality. The second phase concerns the generalization of the suggested algorithm for use in companies with similar production and planning conditions, which is series production within the automotive industry. The third phase then characterizes the possibilities of further development of the suggested planning algorithm. Several variants of the algorithm were assessed within the case study in the real company which took into account specific aspects such as—the obligation of continuous supply to customers, the impact of the gray warehouse zone causing inaccuracies in the records, time-consuming reconstructions of the production line by the product portfolio, etc. At the current stage of development, it is possible to plan production one week in advance on one production line for four products, and two percent of production capacity was saved.

The generalized algorithm (represented in the article as a graphical scheme) brings possibilities of application in similar companies with series production, including expansion to variously numerous product portfolios. Further development of the algorithm is open for the introduction of other functionalities such as—elimination of the gray zone and thus more accurate monitoring of stocks in real-time, more accurate planning of material purchases and thus reducing its inventory, more accurate planning of line stops and related outage planning, etc.

Improving the production efficiency based on algorithmization of the planning process has proven to be successful. There is a potential for further development of this algorithm, which will allow to take more input variables and consider other production equipment, follow-up processes, or storage options.

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