SELECTION OF PRODUCTION TIME FORECASTING METHOD FOR CUSTOMIZED PRODUCTS

M.Sc. Osiński P.1
Department of Management and Production Engineering – Poznan University of Technology, Republic of Poland 1
filip.osinski@put.poznan.pl

Abstract: The article concerns the problem of selection the most suitable method of calculating manufacturing time of products created in Design To Order approach. Product customization is becoming an increasingly important aspect of many companies. The basic problem of this type of production is the determination of time needed for delivery to the customer. Also estimating the duration of individual production operations can be a significant problem for production planning. Without these values, it is not possible to conduct the production planning process without mistakes and faults. The use of common worktime calculation methods is often impossible or inadequate from the point of view of the workload involved during production preparation. The article presents the results of practical research in an enterprise, determining the most effective method of calculating production time in Design To Order approach.

Keywords: WORKTIME CALCULATION, LEAD TIME, TIME STANDARDIZATION, PRODUCTION PREPARATION, PRODUCTION MANAGEMENT

1. Introduction

Requirements of customers, that are related to personalization or customization of products, both in terms of individual needs (desire to stand out) and institutional (the need to use unique solutions) is becoming more important challenge for many manufacturing companies. The need of customization of their products for individual groups or even for individual users significantly affects the production planning possibilities, and thus also its production possibilities. Maintaining high efficiency and efficient production planning processes is necessary to maintain competitive on modern market. The combination of the ability to manufacture products wit unique design or with many configurations for individual users with efficiency similar to mass production, can become a key element for many companies to achieve success on the market and compliance with the concept of an intelligent factory [1][2][3][4][5][6].

The right determination of production capacity is directly related to determination of work time required to produce specific products. Unfortunately, in the case of customized products, determining these values is frequently difficult. A large number of possible configurations of multi-variant products means that the methods of determining production time, used for the serial production, in that case do not apply [7][8]. Due to the growing importance of customization, i.e. pursuit of the maximum match of the product to the customer's expectations, it should be assumed that the scale of variant and DtO production will increase over time, replacing some part of mass production. Multi-variant products are produced on the customer's special order, according to his individual requirements, making them usually not repeatable in a given configuration. The design and technology of manufacturing of individual products has a direct impact on the duration of production process. However, in the case of excessive diversification of individual manufacturing operations, it becomes necessary to use a tool that allows for fast and accurate loading of individual work stations, and thus to develop a production schedule [7][8][9].

Lead time estimation methods can be divided into two basic categories related to the purpose of the method. In the case of unit, variant or low-volume production, summary methods are used, while in the case of mass production, analytical methods are considered most suitable [12, 13, 14, 15].

Summary methods (based on partial times) of work time estimation are based on determining the work time of individual production operations, with dividing the work task into individual stages or moves – depending on the adopted criteria. This group of methods include [15, 16, 17]:

- knowledge-based estimation - setting the time of work by an employee who, based on his own experience, determines the amount of time necessary to perform a given production task
- statistical learning methods - the use of historical data on product performance times or analogous operations
- predictive analytics, comparative method - the use of historical data for similar production operations, taking into account the change in the duration of a given operation by characteristic factors such as dimensions, area, weight of the product or detail subject to processing.

Analytical methods are based on the analysis of individual components of performed production tasks and their duration, determining additional elements that are part of the execution time standard and determining the total time necessary to perform the entire production task.

The analytical and measuring method is also called the research method. The method is based on measuring the implementation times of individual production operations in a given environment (at a given workstation). The tests can be carried out: directly by means of timing, indirectly by observation (photographs) of the work day, or by random sampling (snapshot) [9].

The calculation-analysis method can be carried out in two basic ways. First of them involves specifying in each operation a set of basic movements (activities) and adding up the duration of individual micro movements that make up the given task. The second method allows the calculation of the total time of the production task on the basis of the duration of machining of the manufactured element, taking into account the time necessary to perform all auxiliary activities [17].

The simplified analytical method is based on the division of the production task into individual operations and the determination of the total duration based on the tables of work intensity of typical operations or generally available execution time standards (e.g. welding standards or catalog of material inputs for construction industry).

The production of customized products creates great challenges to the processes of scheduling and production controlling. They have a direct impact on the efficiency of resources held and the achievement of production objectives dependent on costs. Therefore, system solutions are needed for production scheduling, material flow monitoring, and analysis and decision making. As a result of many factors that should be taken into account when preparing the production schedule, it is necessary to implement methods that allow to make dynamic changes [10][11].

Considering the varied requirements of clients, the adopted lead time calculation methods should take into account the possibilities of creating products with different resources. This includes the importance of closely related scheduling to the production preparation process. Additional scheduling processes should be
implemented on the basis of available options of production operations and materials. This can allow to select most effective material flow due to the adopted criteria, eg the use of production resources, the shortest lead time or minimization of inventory [12] [13] [14].

In this context it is particularly important to calculate the precise time standards for the manufacturing processes. The degree of accuracy of these standards has a direct impact on the accuracy of scheduling and production control. On the other hand, it is equally important to limit the time needed to prepare these norms, especially considering the degree of diversity and low repeatability of manufactured products.

2. Case study

The research has been carried out in the SME manufacturing company. The enterprise employs about 25 employees - taking into account small fluctuations resulting from a significant increase in employee mobility on the Polish labor market (employee rotation independent of the employer). 18 of the employees are employed in production positions divided into two departments: electrical (works mostly done manually) and mechanical (turning, milling and welding processes). Other employees are employed in office, including administrative and management positions.

Over 90% of the company's production are unique products with a unique configuration, implemented on the basis of customer orders. The technology of making these products remains unchanged, however, high variability and the possibility of modifying individual product details means that basically any production batch can be considered customized and manufactured in accordance with Design to Order approach. The technological structure of the products consists of 7 basic types, which may differ from each other by elements such as: dimensions, power, type of current output, type of wires, corrosion protection, length of work (heating) zones, assembly method, number and type of technological holes, type of winding, the presence of additional holders and fixings, etc. Each of the mentioned elements can have a significant impact on the complexity of work, and thus on the total duration of the product.

At the beginning of cooperation, the work time necessary to complete individual production orders was estimated by employees with the greatest experience, who were responsible for supervising the work of individual operators (production foremen). Such handling of customer orders implied significant difficulties both in setting the deadline for production of a given order and in assessing the loads on individual workstations. According to the company's data, nearly 76% of orders were carried out with at least 1 day delay, including 23% that had significant delays exceeding 5 business days. During the surveys, long lead times and significant delays were indicated by the company's largest contractors as the biggest problems in cooperation. The inefficiency in loading individual employee positions, however, caused numerous personnel problems related to the lack of a sense of justice of the workload of individual employees. This resulted in reduction of investment of some employees, and an additional decrease in the efficiency of their work, which was particularly noticeable with simple manual work based on repetitive tasks.

3. Research methods

The cooperation undertaken between the Poznań University of Technology and the company was aimed at finding an existing or developing a new method to increase the effectiveness of forecasting the time of production of individual orders. The research began with simulation tests allowing to select several most adequate methods described in the literature. The basic criteria demonstrating the possibility of use of a given method to the enterprise's requirements were considered: the time necessary for implementation, implementation costs, the time necessary to prepare a new production order, and the most important: the accuracy of the obtained results. As a result of the simulation, the methods worth testing in the conditions of the actual production process were: the partial and total statistical method, the simplified partial movement method and the product critical features method.

All of the selected methods have been implemented in a trial in an enterprise in order to obtain results allowing to assess their accuracy, as well as thoroughly analyze the implementation time and preparation time of individual production plan for specific production orders.

The research was divided into stages:
1. Collection of data on work times, preparation times, etc.
2. Collection of data on the technological structure of products and production processes
3. Determination of critical features of products for the duration of individual operations - including preparation and finishing time, number of pieces, etc.
4. Screening thick errors of data collected - caused by errors of employees in recording the duration of operations
5. Development of time standards for partial motions
6. Development of statistical formulas to calculate the duration of individual operations and whole lead time
7. Collecting comparative data to check the reliability of the results obtained from the implemented methods

The first stages of research involving the collection of specific production processes covered 5 months (from April to August 2018). At the time of this study focuses on one of the most popular type of product for which there was an 790 (single production orders). The verification part, however, lasted from October 2018 to the end of April 2019. During this time, 2072 production orders of a given type were recorded. The volume of orders ranged from 1-450 throughout the research, reaching an average order size of 8 pieces during the test period and 6.84 pieces during the verification period.

In order to compare the methods of determining the time necessary to complete a production order, it was necessary to bring the results to a harmonized percentage form, showing the size of the error in accordance with Fig. 1. This was due to significant differences in production times. The shortest lead time for a single unit was 2.5 hours in the examined period, while the longest was 54.3 hours.

\[ E_{m} = \frac{|LT_r - LT_p|}{LT_p} \times 100\% \]

Figure 1 Estimation of error

Where:
- \( LT_r \) – real production time
- \( LT_p \) – estimated production time
- \( E_{m} \) – estimation of error

4. Conclusions

The accuracy of the results obtained in individual methods was estimated on the basis of the average error rate, in accordance with the formula in Figure 1. The values of the average error rates for the entire production process are presented in Figure 2, while the error values for the most important production processes in Table 1. During the tests, the partial movement method due to too much time commitment of employees necessary for each preparation was rejected. In the conditions of the audited enterprise, the time necessary for manual preparation of time standards for each order exceeded the available working time, which resulted in delays already at this stage of production preparation.

Based on the results, it can be concluded that the least accurate method of calculation is the estimation method based on the
operators' experience. The most accurate method is a statistical learning method that uses technological knowledge based on previously implemented processes.

Method based on an analysis of the critical factors of product (predictive analytics) showed significantly worse fit, not exceeding $R^2 = 0.7$. In this analysis, the most important critical features of the product were taken into account, which, according to the operators' experience, had an impact on the duration of their operations (e.g., product volume for core insulation time or total surface area for surface treatment time). However, the model has been greatly simplified in order to speed up development time of a single order, which could cause a decrease in accuracy of the results.

The studies also have taken into consideration a method of estimation knowledge, which is the estimated time required to manufacture the product by foremen. This method, although used so far, proved to be the least effective, which resulted in significant delays in the production plan. The low accuracy of this method may be caused by significant underestimation of working time by the foremen, caused by overestimating the capabilities and skills of employees.

Worth considering is the fact that errors vary considerably depending on the operation being performed. Regardless of the analysis, the biggest error was burdened with time estimation for the core preparation operation. When foremen estimated time, the average error was as much as 34% of estimation. This is due to the fact that this operation is performed mostly manually and its duration is clearly related to the experience of the operator who is performing it. In extreme cases, this operation can take up to 3 times longer than planned by the foreman or 2 times longer than indicated by the statistical method. For comparison, the smallest fluctuations in estimated time occurred in the most homogeneous operations, e.g., quality control, in which the working time is relatively similar regardless of the product variant.

The factor that allows the use of a given method in the case of customized production, not less important than the accuracy of the results, is the time necessary to prepare a single production order. As mentioned earlier, the partial movement method was rejected at the very beginning of practical research. This was due to too much time during its execution. In the case of several dozen orders for new products per day, the time of a single analysis should not exceed a few minutes. In the case of this method, without the use of specialized software written especially for the company, the time of a single study was on average about 36 minutes.

In terms of time, the fastest analysis is the estimation of production time by the most experienced employees. The average time of such analysis can be estimated at 4 minutes. The main problem of this method, however, is the significant risk of its disorders caused by the absence or rotation of the employees responsible for it. The experience of employees in this case is crucial, and their loss can lead to a total loss of control over the production planning process.

The statistical method and predictive analytics ensure relatively good preparation time for the analyzes. As in the case of knowledge estimation, its duration should not exceed 5-6 minutes, if the tools are properly prepared. However, a significant problem with these analyzes is the time needed to implement them. In the case of the examined company, this time was 4 months devoted to collecting data, which seemed an absolute minimum and still does not allow estimation of time for products significantly different from the others. In the case of other enterprises producing customized products, this time may be extended up to 1 year. However, to ensure the best fit of the model, the data collection process should not stop and should be updated as far as possible or include processes such as machine learning.

5. Summary

The production of customized products is a big challenge for modern manufacturers. This type of production requires implementation of many organizational and process solutions to

| Table 1: Accuracy of results in individual production operations |
|-----------------------------------|------------------|------------------|
|                                   | Statistical method (%) | Knowledge estimation (%) | Predictive analytics (%) |
| Steel plate cutting               | 3                 | 9                | 8                |
| Steel bending                     | 8                 | 10               | 9                |
| Welding                           | 10                | 24               | 16               |
| Core preparation                  | 17                | 34               | 24               |
| Current connections               | 12                | 29               | 22               |
| Electrical isolation]             | 11                | 28               | 18               |
| Final assembly                    | 18                | 27               | 22               |
| Quality control                   | 5                 | 8                | 6                |
| **Total**                         | **10,5**          | **21,125**       | **15,625**       |

Figure 2: Average error of the lead time

Figure 2: Correlation between estimated and measured time
meet individual customer requirements. From this point of view, an important issue is the ability to determine production capacity and set possible delivery dates for given orders. For this purpose, it is necessary to have reliable data related to the time of production processes.

The article presents a study comparing three methods of calculating lead time of production process for real life production process. During the study found that the least accurate method is a solution based on operators' experience (knowledge based estimation). The result was expected after simulation tests. Based on the obtained data, it can be stated that the simpler the operation, the tendency to overestimate the results, while the more complex production tasks, the time value is underestimated.

Predictive analytics methods indicate that most important is to determine the correct mathematical dependence that takes into account the critical factors of the product or production operation. In many cases, the relationship based on the unit of measured parameter is not linear.

The most accurate results to real times were obtained for the partial statistical method, with usage of the historical data from already completed production processes.

On this basis, it can be stated that a knowledge base is required to make rational decisions related to the functioning of a production system that meets the individual design requirements of products for customers in the Design to Order approach. However, obtaining this state forces companies to collect and analyze various data indicating the correlations occurring in the process or production system. Thus, enterprises will be forced to enter the path of an intelligent factory striving for the so-called self-learning organization.

Acknowledgments The presented results of the research, carried out under the theme No. 02/23/DSMK/7722, were funded with grants for education allocated by the Ministry of Science and Higher Education in Poland.

References


17. Żurek J., Ciszak O., Cieślak R.: The labor consumption of the assembly process of the real and virtual MTM method. Technologia I Automatyzacja Montaż. 2/2010