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MODELS OF PRODUCTION SYSTEMS AS A CONDITION OF MAINTAINING THEIR STABILITY

Article presents the possibility of using computer modelling and simulation methods for assessing the risk and stability of production systems. Analysis of the stability depending on the occurrence of risk factors was presented through the example of a bogie frames manufacturing plant undergoing reorganization. In order to ensure smooth functioning of a production system, the stability of its processes must be guaranteed, as well as possibility of making fast decisions with the lowest risk rate must be ensured. Products’ and processes’ innovations constitute the ability to remain on the market; however, they incorporate the risk of losing stability. The risk results from the uncertainty associated with making decisions far into the future, as well as from the fact that the implementation of innovations is one of the factors that disturb the current manner of operation of the enterprise. The stability of a production system is defined as maintaining the steady state by the system for a certain period of time.

Key words: production systems, stability, simulation models

1. INTRODUCTION

The concept of stability is derived from the theory of systems. Most definitions found in the literature refer to the concept of the state of balance and define the stability of a system as its ability to return to the state of balance after the termination of disturbances that caused the instability. The stability of a control system is its most important feature that characterizes the ability to accomplish tasks for which it was constructed [2].

The stability of a production system will be understood as maintaining the steady state of the system for a certain assumed period of time. In order to ensure the stability, on the one hand an appropriate control is needed, whereas on the other hand it is necessary to analyze, evaluate and eliminate random factors causing disturbances (risk factors). Control in the context of production systems means making decisions based on the information or data coming from the controlled system. The impact of single- or multi-criteria decisions on the production system

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can be verified very well on a model that contains selected elements of importance in a given context, their parameters and relationships between each other.

Production system modelling allows ensuring the stability of a production system due its ability to:

- understand and assess the impact of the decisions made on the production system including its various functional areas,
- design or reorganize production system in a manner which does not disturb its current and future functioning,
- control production system by selecting the parameters of system inputs in a way that ensures the planned values of the parameters of system outputs,
- identify, assess and eliminate the effect of factors disturbing the correct functioning of the production system.

2. THE ROLE OF PRODUCTION SYSTEMS MODELLING WHILE ENSURING STABILITY

Operations performed on a model instead of the actual production system do not disturb the stability of production processes. Treating a model as a duplicate of the actual system enables – among others – to transfer the conclusions from the studies performed on the computer model to the actual production system. Modelling and computer simulation allow verifying solutions before their actual implementation within the system, which is not possible in the case of conventional methods of conducting design work [1]. An additional advantage is reduction of costs of the changes made on the basis of the simulations carried out at the beginning of the project’s implementation. The changes that have been foreseen and planned at the beginning of the project cost significantly less than those introduced in the later stages, as well as they do not disturb the functioning and stability of the system to a considerable extent [5].

In order to construct a correct decision process for a particular model, it must include the company's aspects which are adequate to the scope of the studies. When modelling production systems, regardless of the purpose of modelling and the optimization criteria adopted, generally six aspects of a manufacturing company are taken into account: management, structures, resources, production processes, basic manufacturing measures and general tasks of the production system [1, 6]. Figure 1 shows the aforementioned aspects along with the elements that are most commonly used in the manufacturing process modelling.
There are many methods and techniques for system modelling, while a broad range of advanced IT packages for process modelling is available on the market [4].

In order to ensure the stability of a production system, an appropriate manner of control is needed, as well as an ability to analyze, evaluate and eliminate the random factors causing the disturbances (risk factors) in the real time. Control, in the context of production systems, constitutes ability to make decisions based on the information or data derived from the system which is being controlled. The impact of single- or multi-criteria decisions on the production system can be verified very well on a model of the production system, which contains important system elements and their parameters as well as the relationships between them.

3. CHARACTERISTICS OF THE PRODUCTION SYSTEM UNDERGOING REORGANIZATION

3.1. Introduction

The project was implemented in the Wroclaw branch of an international corporation engaged in the production of bogies for freight and passenger cars as well as trams. The need for reorganization of the current production system was
caused by a change in the production program associated with a project for adaptation of the plant to the new requirements of the corporation.

The purpose of the introduced improvements was to ensure the stability of the production regardless of the economic conditions, as well as being a result of necessity to expand the factory’s operation and switch the production’s profile from bogies to bogie frames. The restructuring program assumed an increase in the production capacities of the plant from 400 to 1500 pcs of bogie frames a year. The planned production was initially located on a production floor with an area of 10,000 m$^2$, where 10 production lines (bays) were located. Due to the time-consuming changeover, the sizes of products and workstations, as well as specialized instrumentation, each product is manufactured at a different production bay.

### 3.2. Assessing the stability of reorganized production system

Risk factors occur in each production system. With the growth of their impact on the production, they may cause the system to fall out of balance, which would result in loss of continuity of production and hinder achieving assumed goals. However, the risk factors are of random nature, meaning that only after an extended period of time (representative period) a certainty of their occurrence can be assumed. In case of short periods of time, such as one organizational shift, it is not certain which, if any, risk factors may occur. The risk factors were isolated on the basis of direct observations, analysis of the documented orders executed previously, measurements of the processes’ duration, as well as consultations and interviews with employees of different organizational units involved directly in the production process. Table 1 contains information on the identified risk factors.

**Table 1**

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Description of the impact of the risk factor on the production system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td></td>
</tr>
<tr>
<td>Customer ($r_1$)</td>
<td>Customer-specific requirements mean that the customer may demand introduction of constructional and procedural changes in the product. In the analyzed period, this factor applied to 30% of the products and caused an extension in duration of the production process by 9 hours for 1 piece</td>
</tr>
<tr>
<td>Sheet metal supply ($r_2$)</td>
<td>The analysis included the actual quantities and times of deliveries. Because the delays in sheet metal delivery are random, average times and standard deviations were determined for individual deliveries</td>
</tr>
<tr>
<td>Cooperation ($r_3$)</td>
<td>This factor results from delays and poor quality of the components delivered by cooperating partners. The characteristics were determined on the basis of data on rejected or delayed sheets</td>
</tr>
</tbody>
</table>
Table 1 cont.

| Production process \( \left( r_4 \right) \) | An observation was made that there are significant differences between the actual time and the processes’ duration. This is caused mainly by faulty holding devices, failures of overhead cranes, and the time of waiting for the transport of elements. The characteristics were determined on the basis of an analysis of the production documentation, as well as the observations and time measurements performed at the production line. |
| Quality control \( \left( r_5 \right) \) | An analysis of the process showed that 7 % of the manufactured elements had to be repaired, while 3 % were scrapped. The time of repair ranged from 10 minutes to the actual time of production. Since this delay is variable, the analysis assumes that it has a normal distribution. |

For functioning of the production system in the entire plant, functioning of all its components is not a necessary condition. However, correct functioning of one of its areas cannot be regarded as correct functioning of the whole system. The risk of unreliability of one area should translate into an increase in the risk of unreliability of the whole system, exactly by the value of the risk in this area. The formula for the risk for this system should be as follows:

\[
R_C = R_1 + R_2 + ... + R_5
\]

where: \( R_1, R_2, ..., R_5 \) – risk occurring in individual areas of the system.

Individual risks in the analyzed areas of the system \( R_i \) will affect the extent of losses \( (S_i) \) incurred in these areas. These losses are usually expressed as the number of pieces that have not been produced in relation to the number of pieces planned to be produced. Then, the risks for individual areas can be determined from the formula:

\[
R_i = \frac{S_i}{W_{\text{teoret}}}
\]

where: \( S_i \) denotes the loss in the \( i \)-th area of the system, caused by the occurrence of risk factors, while \( W_{\text{teoret}} \) denotes the number of products planned for production in this area.

Analysis of the stability of the production system for variable risk factors during one shift is presented below. Due to the random nature of risk factors, the analysis concerns the occurrence of one and two risk factors. Such a combination will also determine which risk factors have the ability to actually destabilize the system. In addition, it will allow assessing which risk factors disturb the stability of the production system to the greatest extent.

It has been assumed that the system will be stable, if the production volume \( W = 1700 \pm 10 \% \) pcs/year. This value is described as the sum of quantities assumed for production. The analysis of variables on the extent of the impact of individual risk factors was performed using the iGrafix Process for Six Sigma computer modelling and simulation system.
3.3. Assessment of the stability of the production system in the event of the occurrence of a single risk factor

In order to assess the stability of the analyzed production system, a computer simulation model of the system was built. This model did not include any identified risk factors and was named the base model. Characteristics of different types of the risk factors (Table 1) identified were introduced to the base model of all the work centers being analyzed. In this manner, 5 simulation models were created to assess the influence of risk factors on the analyzed production system. Description of the models built is presented in Table 2.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Model description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1. Customer</td>
<td>impact of the risk of customer-specific requirements</td>
</tr>
<tr>
<td>Model 2. Sheet metal supply</td>
<td>impact of the risk of delays and poor quality of the sheet metal supplied</td>
</tr>
<tr>
<td>Model 3. Cooperation</td>
<td>impact of the risk of delays and poor quality of sheet metal from cooperating partners</td>
</tr>
<tr>
<td>Model 4. Production process</td>
<td>impact of the risk of differences between the process times and actual times, and the risk of failures</td>
</tr>
<tr>
<td>Model 5. Quality control</td>
<td>impact of the risk of manufacturing defective products</td>
</tr>
</tbody>
</table>

The results obtained from the experiments conducted with the use of the models presented in Table 2 are shown in Figure 2.

Figure 2. The impact of a single risk factor on the analyzed production system
As shown in Figure 2, if risk factors occur one at time, the system will lose its stability only in the case of the risk associated with the differences between the process times and actual times, as well as in the case of risk of machine failures. In such an event it will not be able to produce the quantity of products assumed in the production plan.

### 3.4. Assessment of the stability of the production system in the event of the occurrence of two risk factors

The next step involved examining the stability of the production system in the event of the occurrence of two risk factors. As in the case of the analysis of two risk factor, the base model was used, but it was modified with the characteristics of two types of risk factors. The risk factors associated with the production process and the customer were excluded from the examinations, because, as it appears from previous studies (Figure 3), a single occurrence of these risk factors results in the loss of production system's stability. It was built following models to analyze the stability of the production system containing two risk factors: Model 1 – Sheet metal supply + Cooperation, Model 2 – Quality control + Cooperation and Model 3 – Sheet metal supply + Quality control. The results obtained from the experiments conducted with the use of the models are shown in Figure 3.

![Figure 3. Impact of a combination of two risk factors on the analyzed production system](image)

As is presented in Figure 3, if any combination of two risk factors occurs, the analyzed production system will fall out of balance. As can be seen, if the production organization level is not improved, the risk factors occurring in the system will hinder the assumed goal.
W artykule przedstawiono możliwość wykorzystania modelowania i symulacji komputerowej do oceny ryzyka i stabilności systemów produkcyjnych. Zdefiniowano pojęcie stabilności w kontekście realizacji zadań zaplanowanych dla systemów produkcyjnych. Na przykładzie reorganizowanego zakładu produkującego ramy wózków przedstawiono analizę stabilności w zależności od występowania czynników ryzyka. Analiza stabilności systemu produkcyjnego dotyczyła wystąpienia pojedynczego czynnika ryzyka oraz kilku czynników równocześnie. Tego typu analiza umożliwia ocenę wpływu czynników zakłócających na osiągnięcie celów stawianych przed systemem produkcyjnym.

Słowa kluczowe: systemy produkcyjne, stabilność, modele symulacyjne

MODELE SYSTEMÓW PRODUKCYJNYCH
JAKO WARUNEK ZAPEWNIENIA STABILNOŚCI

Streszczenie

W artykule przedstawiono możliwość wykorzystania modelowania i symulacji komputerowej do oceny ryzyka i stabilności systemów produkcyjnych. Zdefiniowano pojęcie stabilności w kontekście realizacji zadań zaplanowanych dla systemów produkcyjnych. Na przykładzie reorganizowanego zakładu produkującego ramy wózków przedstawiono analizę stabilności w zależności od występowania czynników ryzyka. Analiza stabilności systemu produkcyjnego dotyczyła wystąpienia pojedynczego czynnika ryzyka oraz kilku czynników równocześnie. Tego typu analiza umożliwia ocenę wpływu czynników zakłócających na osiągnięcie celów stawianych przed systemem produkcyjnym.

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