Assessment of Production System Stability with the Use of the FMEA Analysis and Simulation Models

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Abstract. In order to ensure smooth functioning of a production system, the stability of its processes must be guaranteed, while on the other hand it must be possible to make quick decisions encumbered with the lowest possible risk. The risk results from the uncertainty associated with making decisions as to 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 assumed period of time. The paper describes a method for analysing and assessing the stability in production systems. In order to determine the extent of the impact of individual risk factors on the selected area of the production system, the FMEA analysis was used. When determining the values of the parameters needed for calculating the Risk Priority Number (RPN), defuzzified values of appropriate linguistic variables were used. A process of ore transportation process with the use of a belt conveyor was used as an example.

Keywords: Stability · Production system · Modelling and simulation · FMEA analysis

1 Introduction

The concept of stability is derived from the systems theory. 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 disturbances that caused the instability have ceased. The stability of a control system is its most important feature that characterizes the ability to accomplish the tasks, for which it has been built [1].

If the value of the parameter P(ti), which characterizes the production system at the time t_i, is within the predetermined interval $P_1 \leq P(t_i) \leq P_2$, this will indicate a correct course of the process. Otherwise, corrective measures should be taken. Corrective measures usually consist in changing the values of control variables (inputs to the system) in such a way, so that the values of the parameters characterizing the controlled variables (outputs from the system) return to the process course standards established at the planning stage [1]. Production plans and parameters characterizing them usually constitute the standards. A correct decision will cause that the system will return to the steady state.

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So it can be said that a production system is in the steady state, if values of the parameters defining it are within the ranges specified in the planning function and recorded in a standard, i.e. a production plan, as schematically shown in Fig. 1.

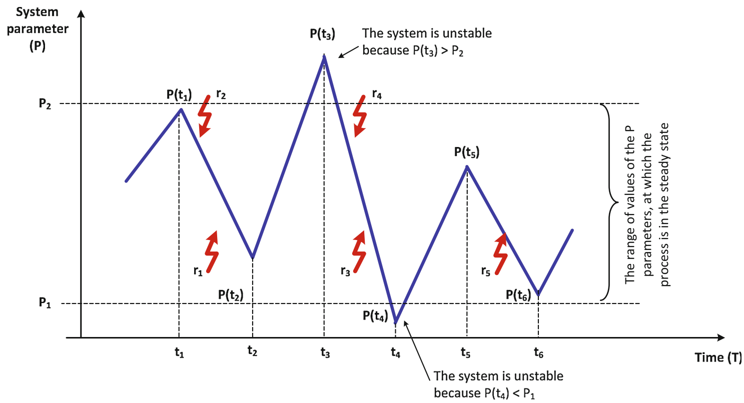

Fig. 1. The variability of the system parameter $P(t_i)$ is caused by the impact of disturbing factors (r_i)

In order to ensure the stability of production systems, on the one hand an appropriate control is needed, while on the other hand it is necessary to analyse, evaluate and eliminate the random factors causing the 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 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.

2 The Role of Production Systems Modelling in Ensuring the 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, inter alia, the transfer of the conclusions from the studies performed on the computer model to the actual production system. Modelling and computer simulation allow verifying solutions being introduced before their actual implementation, which is not possible in the case of conventional methods of conducting design work [2]. An additional advantage is a reduction in the costs of the changes made on the basis of the simulations carried out at the beginning of the project implementation. The changes, which have been foreseen and planned at the beginning of the project, cost significantly less than in the later stages and they disturb the functioning and stability of the system to a lesser extent [3, 4].

In order to be able to make right decisions based on a model, it must include the company's aspects adequate to the scope of the studies. When modelling production systems, regardless of the purpose of modelling and the optimization criteria adopted, generally six aspect of a company are taken into account: management, structures, resources, production processes, basic manufacturing measures and tasks of the production system [2]. Figure 2 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 in the market [3, 5–7]. Production system modelling allows ensuring the stability of a production system due to the possibility of:
- understanding and assessing the impact of the decisions made on the production system including its various functional areas,
- designing or reorganizing the production system in a manner that does not disturb its current and future functioning,
- controlling the production system by selecting the parameters of system inputs in such a way, so that the planned values of the parameters of system outputs are ensured,
- identifying, assessing and eliminating the effect of factors disturbing the correct functioning of the production system.

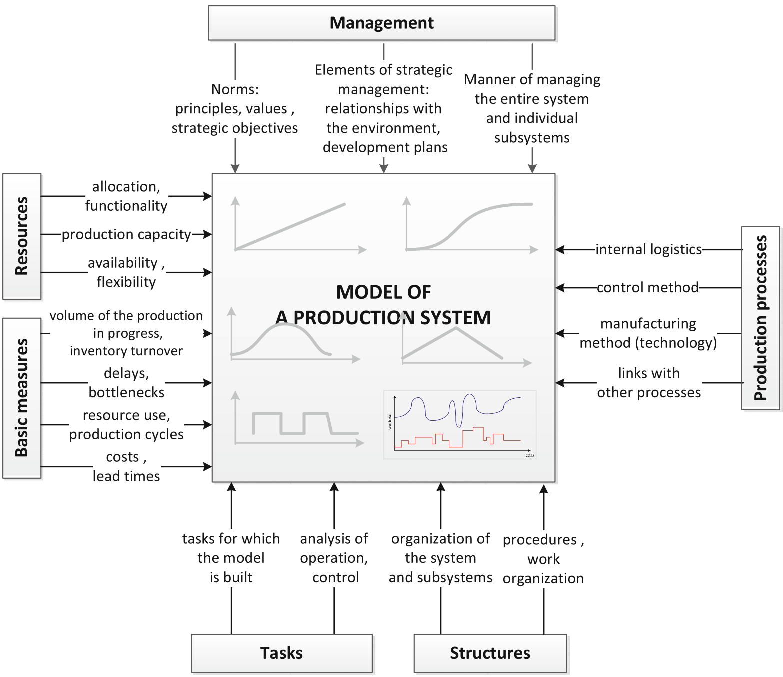

Fig. 2. Production system modelling usually takes account of parameters, an aggregated model of a production company, as well as selected components.

3 Identification and Assessment of Risk in Production Systems

In order to reduce the level of risk in a production system, a series of actions must be taken. The first of them is the risk identification, which determines the threats that might occur during realization of company's goals. Due to a potential possibility that many risk factors may occur, it is important to find the source risk, which is the key cause of the problems. During the identification, it is important to search for the answers to the following questions: in which area of the production system the risk occurs and which area is affected by the highest risk.

The next step in reducing the risk level is measuring the risk and determining the extent of the impact on the production system. Failure Mode and Effect Analysis (FMEA) is one of the methods which allow determining the extent of risk in the designated area of a production process or in a product, as well as the resulting effects. Thanks to this, corrective actions aiming at mitigation of the risk can be found subsequently [8]. *"One of the key factors in proper implementation of the FMEA program is to act before an event occurs and not to gain experience after the event. In order to obtain the best results, FMEA should be performed before a particular type of construction or process defect is "designed" for a given product.*" [3].

3.1 Determination of the Risk Priority Number (RPN) in the FMEA Method

When assessing the risk in a production process with the use of the FMEA method, the first step is to detail the operations in the process, then to identify the risk factors present in the process, determine the effects caused by their presence, and to find possible causes. The next step in the analysis is to assign numerical values to the following parameters shown in Table 1.

Table 1. Characteristics of the parameters used in the FMEA method for determining RPN

Parameter symbol	Parameter name	Description
Z	degree of threat	It determines the extent of the effects which arise as a result of the occurrence of a defect during a production process and during the use of a product
P	probability	The probability of the occurrence of a defect
T	detection rate	It determines the probability that a potential defect or its cause will be detected later

Risk Priority Number (RPN), i.e. the extent of the risk, is calculated for each of the selected areas of the production system using the formula [3]:

$$RPN = (Z) \times (P) \times (T) \tag{1}$$

This obtained value allows assessing the estimated risk and is used as a point of reference in relation to the corrective actions taken. The value of RPN may be in the range between 1 and 1000. So a high value of RPN corresponds to a high risk in the process. If the RPN value is high, efforts should be taken to mitigate the risk using corrective actions [3]. The corrective actions shall be taken first in the areas with the highest RPN level.

Figure 3 shows 4 areas representing a area of high losses and risk. These areas are presented together with the parameters described above.

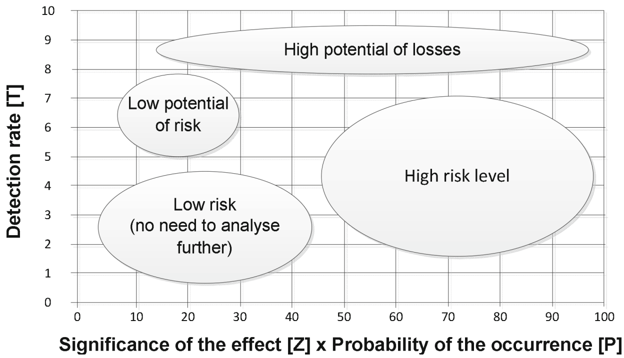

Fig. 3. The results of the RPN analysis depending on values of the parameter

Determination of a general limit for a high RPN value is not easy. Each FMEA analysis is unique and the risk estimation in this method cannot be compared with other analyses. This is caused by some sort of subjectivity, the dependence during the assessment, and the decisions made by the person performing the analysis. Therefore for each FMEA analysis a system of criteria should be developed and it should be determined from which values of RPN the corrective actions should be taken [3]. In the era of dynamic changes in the market environment, the FMEA method proved to be a good alternative solution that enables quick identification of potential risks for a company.

4 Determination of Risk in the Process of Haulage of Excavated Material by Belt Conveyors, Using Linguistic Variables

Belt conveyors are mechanical means of transport with a limited range and continuous movement. Typically they are used for conveying bulk materials. Material is transported on a specific route limited by the distance between the loading and unloading stations. Depending on the construction, material can be transported along a straight line or a curve, at any angle. Belt conveyors are characterized by simple construction, high reliability and safety.

The problem of failures of belt conveyors was subjected to an analysis. This is a very important issue in respect of transportation of excavated material in a mine, because failures lead to unplanned downtimes and thus to stopping the haulage of excavated material for several shifts. On the other hand, the information about a failure may come from production workers only, which results from the conditions occurring in a mine, the length of the transport system and provisions of the mining law. Information about a failure was verbal and depended on individual impressions of workers.

The FMEA analysis was prepared on the basis of the stages of the process of transportation by a belt conveyor and the risk factors. (Table 2) shows the FMEA analysis performed only for first stage of the belt conveyor operation – start-up.

Table 2. FMEA analysis of two stages of the belt conveyor operation

Opera-tion /Process stage	Possible risk factors	Effects caused by the risk factors	Current state			
			Risk factor assessment (P) [rank]	Effect assessment Z [rank]	Hazard assessment T [rank]	RPN
Start-up of the belt conveyor	Transmission system failure	Gearbox failure	5	8	2	80
		Coupling failure	5	8	3	120
		Motor failure	6	7	3	126
		Pulley failure	6	6	5	180
	Belt damage	Belt breakage	5	9	2	90
		Belt slip-off	5	9	7	315

5 Assessing the Stability of Haulage of Excavated Material by Belt Conveyors, Using Linguistic Variables and Simulation Models

An analysis of the stability of the production system for different variants concerning the occurrence of risk factors during one shift is presented below. Due to the random nature of risk factors, the analysis will concern the occurrence of one and two risk factors. Such a combination will also give an answer to the question at which variants of the occurrence of risk factors the system will remain stable and at which not. In addition, it will be possible to assess 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 transportation volume of excavated material W = 2500 ± 10 % tons/week. The analysis of variants of the studies on the extent of the impact of individual risk factors was performed using the iGragix Process for Six Sigma computer modelling and simulation system.

Thanks to the use of IT systems, models were populated with appropriate data from an actual system. Modern production systems are measured and monitored to a higher and higher degree. The experiments conducted on models do not disturb the functioning of the actual system and thus allow predicting the effects as well as selecting an optimal variant of decisions on the parameters and types of inputs to the system.

In order to assess the stability of the analysed 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. Values of different types of the risk factors (Table 2) identified in FMEA analysis were introduced to the base model. In this way, 2 simulation models were created to assess the influence of risk factors on the analysed production system (Table 3).

Table 3. Two models used for analysing the stability of the production system depending on the occurrence of a single risk factor

Model name	Model description
Model 1.	impact of the risk of transmission system failure
Model 2.	impact of the risk of belt damage

The results obtained from the experiments conducted with the use of the models presented in Table 3 are shown in Fig. 4.

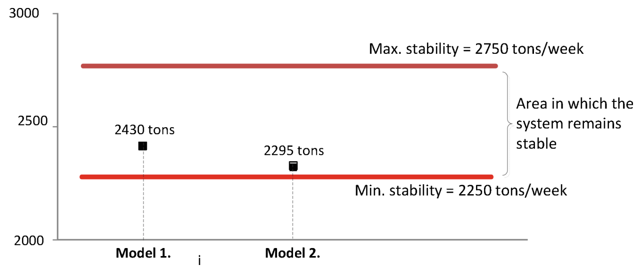

Fig. 4. The impact of a single risk factor on the FMEA analysed production system

As shown in Fig. 4, if risk factors occur one at time, the system will be stability.

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 a single risk factor, in the base model were introduced two types of risk factors identified in FMEA analysis. The results obtained from the experiments conducted with the use of the model presented are shown in Fig. 5.

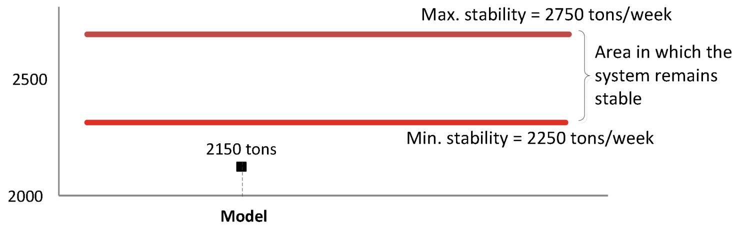

Fig. 5. The impact of a combination of two risk factors on the FMEA analysed production system

As is appears from Fig. 5, if any combination of two risk factors occurs, the analysed transportation system will become out of balance. As can be seen, if the production organization level is not improved, the risk factors present in the system will prevent the accomplishment of the assumed goal.

6 Conclusion

Smooth operation of a production system is a phenomenon that occurs less and less often. It happens more and more frequently that the attention is drawn to the need of detecting the threats early and collecting the information concerning the cause-effect relationships occurring in the system. The FMEA analysis helped to determine the cause-effect relationships associated with the occurrence of risk factors and then minimize their impact on the production system. Proposed in literature quantitative methods of risk analysis and evaluation treat single issues, assuming certain factors and conditions as well as impose constraints. Taking into consideration the complexity of modern production systems as well as a number of influencing them external, random factors, this kind of approach seems to be unsuitable.

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