Evaluation of the Risk in Production Systems with a Parallel Reliability Structure Taking into Account Its Acceptance Level

Anna Burduk

Wrocław University of Technology, ul. Wybrzeze St Wyspianskiego 27,
50-370 Wrocław, Poland
anna.burduk@pwr.wroc.pl

Abstract. Proposed in literature quantitative methods of risk analysis and evaluation treat single issues, assuming certain factors and conditions as well as impose constraints. Hence in order to asses risk of production process in its real environment, the problem should be simplified and adjust to a certain method. 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. This paper presents a method of determining the risk for a production system and a coefficient of changes' risk.

Keywords: Risk, production system, reliability, reliability structure.

1 Introduction

The questions of reliability traditionally concern problems connected with functioning of technical objects, and this term is very rarely used in relation to economic systems. In the economics literature, there is a considerable interest in the subject of risk. Since, according to the systems theory, the term "system" can refer both to technical and economic objects, it seems to be justified to transpose the general reliability theory to the sphere of economics and its use in risk planning and evaluation.

The general reliability theory defines reliability of an object differently from the classical theory. "A reliable object is an object, which functions in accordance with user's intentions, while an unreliable object is each object, which functions inconsistently with user's intentions" [1]. Specificity of production systems and, in particular, their complexity, allows treating them as operation systems, and then the reliability is one of their features measured by the extent of realization of determined indicators, parameters and characteristics. The most frequently analysed indicators of a production process include [2]: duration (t), efficiency (W) and productivity (P).

Transposition of the general reliability theory to the sphere of production systems can take place by treating unreliability (Z) – the opposite of reliability – as a synonym of risk (R) [1]:

$$R = Z \; . \qquad (1)$$

E. Corchado, M. Kurzyński, M. Woźniak (Eds.): HAIS 2011, Part II, LNAI 6679, pp. 389–396, 2011.

For this interpretation, the following equation should be true:

$$N + Z = 1. \tag{2}$$

This equation means that the probability that the system is in the state of reliability or unreliability is 1. In the face of the above, the following equations are also true:

$$N + R = 1 \text{, and hence } R = 1 - N. \tag{3}$$

Analysis and evaluation of risk will allow determining reliability of system functioning and vice versa. Despite the fact that the reliability approach in risk planning and evaluation offers more possibilities, it does not locate the risk factors in the system. Analysing the structure of a production system in the context of its reliability structure may provide a solution to this problem.

2 Reliability Structure of Systems

The structure of the system, which determines the relation between the state of reliability of the system and the state of reliability of its objects [1]. The analysis of the reliability structure of a system should be preceded by dividing the system into individual components – the system decomposition, which should reflect the logical connections in the system. In this paper will be presented only a parallel structure of production . Serial structures have been described, inter alia, in [3], [4].

According to the definition of the reliability of a system with a parallel structure says that the system is fit for operation, if at least one of its objects is fit for operation [1]. In the production practice, there occur parallel structures, however the nature of a production process does not allow for such interpretation of the reliable structure. The classical theory of reliability considers 0/1 states of technical equipment. This means that a production system would be recognized as reliable, if at least one element functioned correctly. In production systems, such a situation occurs only in so-called redundant systems, i.e. with a surplus of elements functioning in the system. In reality, redundant systems occur very rarely, because surplus of elements (e.g. machines, workers) means unused resources, which increased costs. Because production systems with redundancy occur in the production practice very rarely, a different way of interpreting and determining the risk for so-called parallel structures of production was proposed in this study. An example of the parallel structure of production can be the structure of the production system presented in Fig. 1.

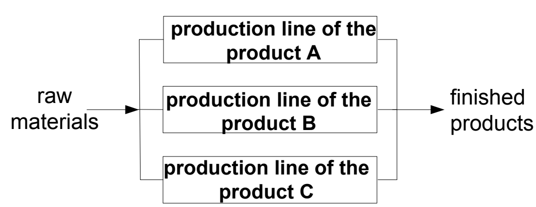


Fig. 1. An example of the parallel structure of production

For the n-element structure of the production system shown in Fig. 1, the risk of unreliability of one element R*i* should increase the total risk R_C^{PSR} of the system by the value R*i*. S*o*, the total risk should be the sum of risks of individual system elements.

$$R_C^{PSR} = R_1 + R_2 + ... + R_n = \sum_{i=1}^{n} R_i \ . \tag{4}$$

where R_1, R_2, R_n - the risk occurring in individual objects/subsystems of the system. If $\sum R_i > 1$, then $R_1 = R_1 / R_C^{PSR}$, $R_2 = R_2 / R_C^{PSR}$, $R_n = R_n / R_C^{PSR}$.

Individual risks R_i for n areas, depending on the amount of losses S_i incurred in these areas, will be as follows:

$$R_1 = \frac{S_1}{W_{teoret}}, \quad R_2 = \frac{S_2}{W_{teoret}}, \quad R_n = \frac{S_n}{W_{teoret}} \ . \tag{5}$$

where S_i – means a loss at the area *i* caused by occurrence of the risk factor r_i.

W_{teoret} – maximum value a selected indicator, which can be attained in theory (for example, theoretical capacity of a machine).

If the areas differ from each other, it is necessary, in case of such a type of structure, to determine the maximum value of the indicator attainable in the analysed technical system - W_{teoret} for each area. When determining the values of W_{teoret} for each of the *n* examined areas, individual losses S_i in these areas, depending on the time losses caused by occurrence of risk factors in individual areas, will be as follows:

$$S_1 = W_{teoret}^1 \frac{\Delta t_1}{T}, ... \ S_2 = W_{teoret}^2 \frac{\Delta t_2}{T}, ... \ S_n = W_{teoret}^n \frac{\Delta t_n}{T} \ . \tag{6}$$

where: W_{teoret}^i - means theoretical value of an indicator in individual areas of the decomposed system.

So, the total risk R_C^{PSR} for a system with n areas and parallel structure of production will be as follows:

$$R_C^{PSR} = \frac{W_{teoret}^1 \Delta t_1 + W_{teoret}^2 \Delta t_2 + ... + W_{teoret}^n \Delta t_n}{W_{teoret} T} \ . \tag{7}$$

If examined areas of the system are identical and are characterized by the same value of W_{teoret}^i , that is:

$$W_{teoret}^1 = W_{teoret}^2 = ... = W_{teoret}^n = \frac{W_{teoret}}{n} \ . \tag{8}$$

then the formula for the total risk of such a system will take the following form:

$$R_C^{PSR} = \frac{1}{nT} \sum_{i=1}^{n} \Delta t_i \ . \tag{9}$$

In accordance with the formula (4), the formula for the risk of the system from Fig. 1, will be as follows:

$$R_C^{PSR} = R_{lpwA} + R_{lpwB} + R_{lpwC} = \sum_1^3 R_{lpwi} \ . \tag{10}$$

where l_{pwA}, l_{pwB}, l_{pwC} – individual production lines of a product.

3 Risk Acceptance Coefficient

At given organisational, technical and technological conditions the amount of risk of a given production system is constant. In case, when in one of areas/subsystems of a system the risk level is too high (unacceptable), one can try to lower the level of risk in that area, being denoted by i. Then however, risk levels in other areas/subsystems might alter, what is followed by necessary technological changes in other areas.

Change in level of risk - in individual areas/subsystems of a production system – down to a acceptable level can take place in a proportional or weight way.

3.1 Proportional Coefficient of Risk Changes

When using the proportional coefficient of risk changes, first and foremost one has to determine the level of risk, which is going to be acceptable in a given area/subsystem and where $R_i > R_{i\_akcept}$.

Proportional coefficient of risk changes WP will be determined as follows:

$$WP = R\_zm \frac{1}{n-1} \ . \tag{11}$$

where $R_{\_zm}$ – value of risk change within an entire system, n – number of areas/subsystems in a production system.

After taking into account the proportional coefficient of WP changes, risks in individual areas/subsystems will present as follows:

$$R_1 = \frac{S_1}{W_{teoret}}(WP+1) \ , \ R_{n-1} = WP \frac{S_2}{W_{teoret}}(WP+1) \ ,..., \ R_{n+1} = \frac{S_2}{W_{teoret}}(WP+1),$$
$$R_n = WP \frac{S_n}{W_{teoret}}(WP+1) \ . \tag{12}$$

3.2 Weight Coefficient of Risk Changes

When using the weight coefficient of risk changes one can assume various alterations in risk levels in particular k areas, where $k \neq i$. The value of coefficients of changes in individual areas needs to satisfy the expression:

$$R\_zm = WP_1 + WP_{n-1},...,WP_{n+1} + WP_n \ . \tag{13}$$

After taking into account the weight coefficient for every area, risks in individual areas/subsystems will present as follows:

$$R_1 = \frac{S_1}{W_{teoret}}(WP_1 + 1)\,,\ R_{n-1} = \frac{S_2}{W_{teoret}}(WP_{n-1} + 1)\,,\ldots,$$
$$R_{n+1} = \frac{S_2}{W_{teoret}}(WP_{n+1} + 1),\ R_n = WP\frac{S_n}{W_{teoret}}(WP_n + 1)\,. \qquad (14)$$

4 Example of Determining the Value of Risk for a Production System with a Parallel Structure of Production

The project was carried out in the Wrocław division of an international corporation. This Division is the third largest division within the corporation and it deals with production of electric locomotives, freight cars and subway cars.

The necessity of analysing production processes of 11 different products was a considerable difficulty. However, as both the production technology and organization of all production processes in the plant are similar, it was decided to perform the analysis for a representative product and to apply so called conversion factors in relation to other products. These factors determine the constructional and technological similarity in relation to the design, which is known and is deemed to be representative. As all production processes in the company are similar to the process of the representative product, it has been assumed that the same risk factors occur also in other processes.

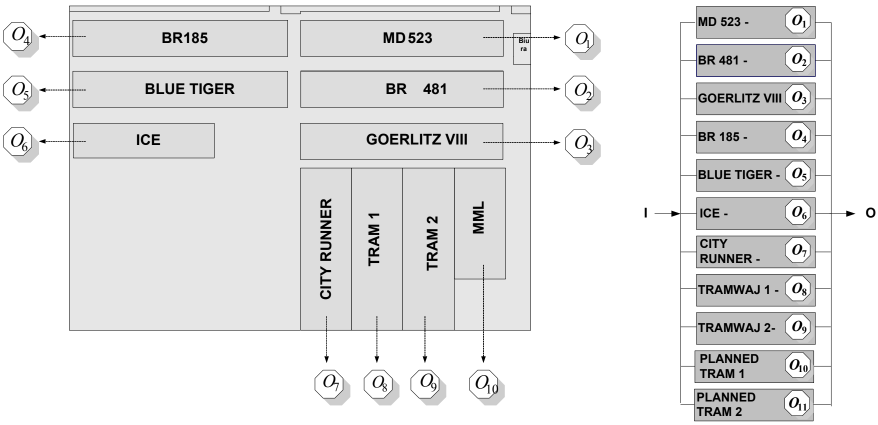
4.1 A Method of Determining the Value of Risk for a Production System with a Parallel Structure of Production

For functioning of the production system in the whole plant, functioning of all its areas is not a necessary condition. However, correct functioning of one area 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. Therefore, it has been established that the reliability structure of the whole plant will be a parallel structure of production (presented in Fig. 2b).

So, when setting a goal for a production system, there should be considered the theoretically attainable production capacity, and not the quantities resulting from the sales plan. For production systems, the theoretical value is limited only by technological capabilities [5].

Therefore, taking into account only the times of production and transport, under the assumption that the system is fully reliable, resources are fully available, and the load of production lines is 100%, the theoretically attainable production capacity (W_{teoret}) for individual lines was set as the goal and was presented in table 1.

Since risk factors are of random nature and the period of observations provided a representative set of data, this period was accepted as representative for determining characteristics of risk factors [6]. The annual pool of working time for the plant is 46 weeks, for T=3 months= 12 weeks. Table 3 presents the data needed for determining the total risk R_C^{PSR} of the whole plant.



a) b)

Fig. 2a). Designations accepted for areas of the production system of the whole plant, **b)** parallel structure of production assumed for the analysed plant

Table 1. Data required in the method

Project name	Conversion factor	W_{teoret} / T	R_i	Δt_i taking into account the conversion factor and the quantity planned for production
BR 185	1.7	35	R_4	5.17
Blue Tiger	1.9	17	R_5	2.81
ICE	1.6	52	R_6	7.23
MD 523	1	138	R_1	12
Goerlitz VIII	1.4	104	R_3	12.66
BR 481	1.2	69	R_2	7.20
Cityrunner, Tram 1, Tram 2	1,1	35	R_7, R_8, R_9	3,35
Planned 1, Planned 2	0.4	35	R_{10}, R_{11}	1.22

Using the formula (7) values of losses in individual areas, which are equivalent to products, were determined. Knowing the value of losses from the formula (6) the risks for the examined areas can be determined.

It was assumed that the level of risk acceptance for the MD 523 product equals 0.1. By means of proportional coefficient of risk changes based on the formula (11), levels of risks were found in individual areas of the analysed system. Additionally for individual are of the production system weight coefficients were assumed and based on the formula (12) for weight coefficient of risk changes, levels of risk were determined for individual areas of the analysed production system. Obtained in that manner values are presented collectively in the table 2.

Table 2. Values of losses and risks for individual products

Project name	Area design ation	Losses [pcs/12 weeks]	Risks	Level of risks after applying WP	Values of assumed weight coefficients	Levels of risks after applying *R_zm*
BR 185	O4	10.61	0.018	0,020	0	0,018
Blue Tiger	O5	2.92	0.005	0,006	0,1	0,006
ICE	O6	22.35	0.038	0,041	0,1	0,041
MD 523	**O1**	**99.1**	**0.168**	**0,100**	**-**	**0,100**
Goerlitz	O3	78.23	0.133	0,138	0	0,133
BR 481	O2	29.73	0.051	0,054	0,1	0,054
Cityrunner	O7	6.86	0.012	0,013	0,1	0,013
Tram 1	O8	6.86	0.012	0,013	0,1	0,013
Tram 2	O9	6.86	0.012	0,013	0,2	0,015
Planned 1	O10	2.5	0.004	0,006	0,1	0,006
Planned 2	O11	2.5	0.004	0,006	0,2	0,008

Obtained levels of risk before and after application of coefficients of risk acceptance are combined together in Fig.3.

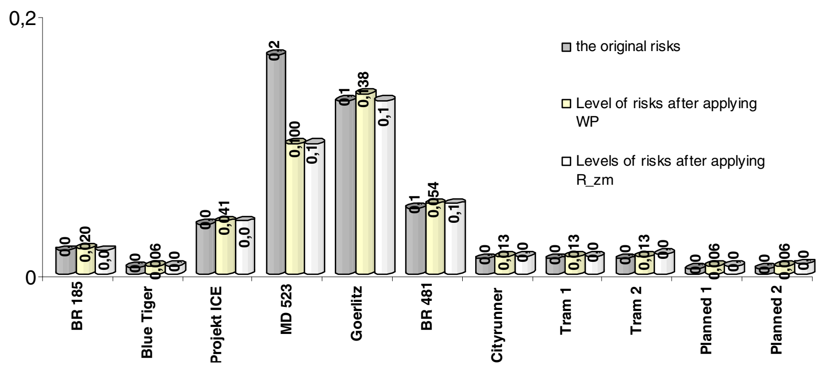


Fig. 3. Value of risk for individual products

When calculating the total risk for the whole plant R_C^{PSR}, the formula (4) should be used. Then the total risk will be:

$$R_C^{PSR} = R_1 + R_2 + \ldots + R_{11} = \sum_{i=1}^{n} R_i = 0{,}46\,.$$

The level of the risk of the entire plant in relation to the risk of the representative product decreased.

5 Conclusion

The production system was defined in accordance with systems theory, while the risk was treated as a synonym of unreliability. This approach allowed decomposing the production system into several areas and determining the reliability structure of the production system. This paper presents a method of determining the risk for a production system with a parallel structure. Additionally weight and proportional coefficient of changes' risk was introduced. The method of determining the risk for a parallel structure of production was verified in a production company, which manufactures bogie frames for railway cars, trams and railway engines.

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