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Calculation of failure criticality in Reliability - Centred Maintenance

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The paper presents methodology for calculation of criticality of failure of components of technical systems in reliability-centred maintenance. Criticality of failure is complex function that depends on the adopted criteria: safety, standstill duration, quality of system functions during the malfunction, total costs and frequency of failures. Depending on characteristics of the analyzed system, the criteria for calculation of criticality may be extended or reduced, and the degree of their influence may be increased or decreased. The proposed methodology is applied to the case of pump station for water supply.
Keywords: Criticality, RCM, FMECA, Risk Priority Number, Pump station

0 INTRODUCTION

The majority of modern maintenance strategies contain RCM (Reliability Centred Maintenance) analysis. Many authors classify RCM into maintenance strategies.

The leading theorist of RCM (Reliability Centred Maintenance) methodology, John Moubray, defined RCM as a process that is essentially the same as FMECA (Failure Modes, Effects and Criticality Analysis). The difference is that in it the manufacturer sums up its knowledge about potential failures and RCM summarizes several years of experience of operators and those who maintain the equipment.

The analysis of mode and effects of failures (FMCA) is the procedure for the estimation of reliability of the device in all phases of its operating circle, which is based on observing all potential failures of items and their effects on the device. FMEA is a systematical technique and formal help in thinking which enables the weak places in technical system known from the experience, the potential failures, consequences and risks, to be seen on time, and to be brought into the process of decision making together with measures of corrective maintenance

By identifying characteristics of technical systems and quantitative assessment of factors of occurrence, the consequences and nondetection of the cause of failure, with the risk priority index - R (Risk Priority Number - RPN), the identification of the weak and the risky places in the system is enabled. Risk priority index for all causes of potential failure modes is obtained by multiplying the partial values of risk factors. In this way calculated values of risk factor R are compared with critical values of RPN, which is determined by common consent of FMEA team.

1. RCM ANALYSIS

Before commencing a comprehensive RCM analysis and defining of requirements, it is necessary to establish a detailed catalog of technological systems that are the subject of maintenance, as well as conducting detailed familiarization with the production process. After implementation of these two necessary steps, for each of the defined technological systems it is necessary to ask the seven basic questions / requests of RCM conception and provide detailed answers for each one of them.

These seven questions are:

1. Which functions of equipment are essential in the current exploitation?
2. Which equipment failures can occur?
3. What are the causes of failure?
4. What happens when there is a failure?
5. How important is each failure?
6. What can be done to prevent a failure?
7. What to do, if you can not find a suitable preventive action?

1.1 Effects of failure modes in RCM

After making the list of failure modes for each of the components of the system and finding a functional dependence between all failure

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modes of components and functional failures, it is necessary to determine the impact of each failure mode at the local level, system level and the level of the plant. Such decisions are not at all simple, so that is why logic tree of decisions shown in Figure 1 is used.

In this way classified failure modes can be placed in one of the three branches of the logic tree (algorithm, figure 1): EVIDENT, SAFETY andOUTAGE. Classification of the effects of failure modes according the logic tree of decisions classifies each failure mode to one of four groups:

A - safety problem
B - problem of outage
C - minor (insignificant) economic problem
D - hidden failure

From this analysis, given the huge number of combinations that can occur when the failure modes and their causes are concerned, once again the necessity for forming a database of failures is confirmed.

2. FMEA AND FMECA ANALYSIS

FMEA is a basic process for qualitative assessment of the reliability of technical systems. Logical continuance of FMEA is quantifying of appropriate values relating the failure of the elements of technical systems and review of criticality. Upgrading of FMEA, related to the assessment of the degree of criticality of components to the system or mission of the system is called criticality analysis (Criticality Analysis CA) [4,5]. By the term criticality it is usually meant a relative measure of consequences of failure modes, and frequency of its occurrence. The joint analysis of FMEA and CA is called the analysis of failure modes, effects and criticality (Failure Modes, Effects and Criticality Analysis - FMECA). All general considerations regarding FMEA, also apply to FMECA, because this method is the continuation of the previous one.

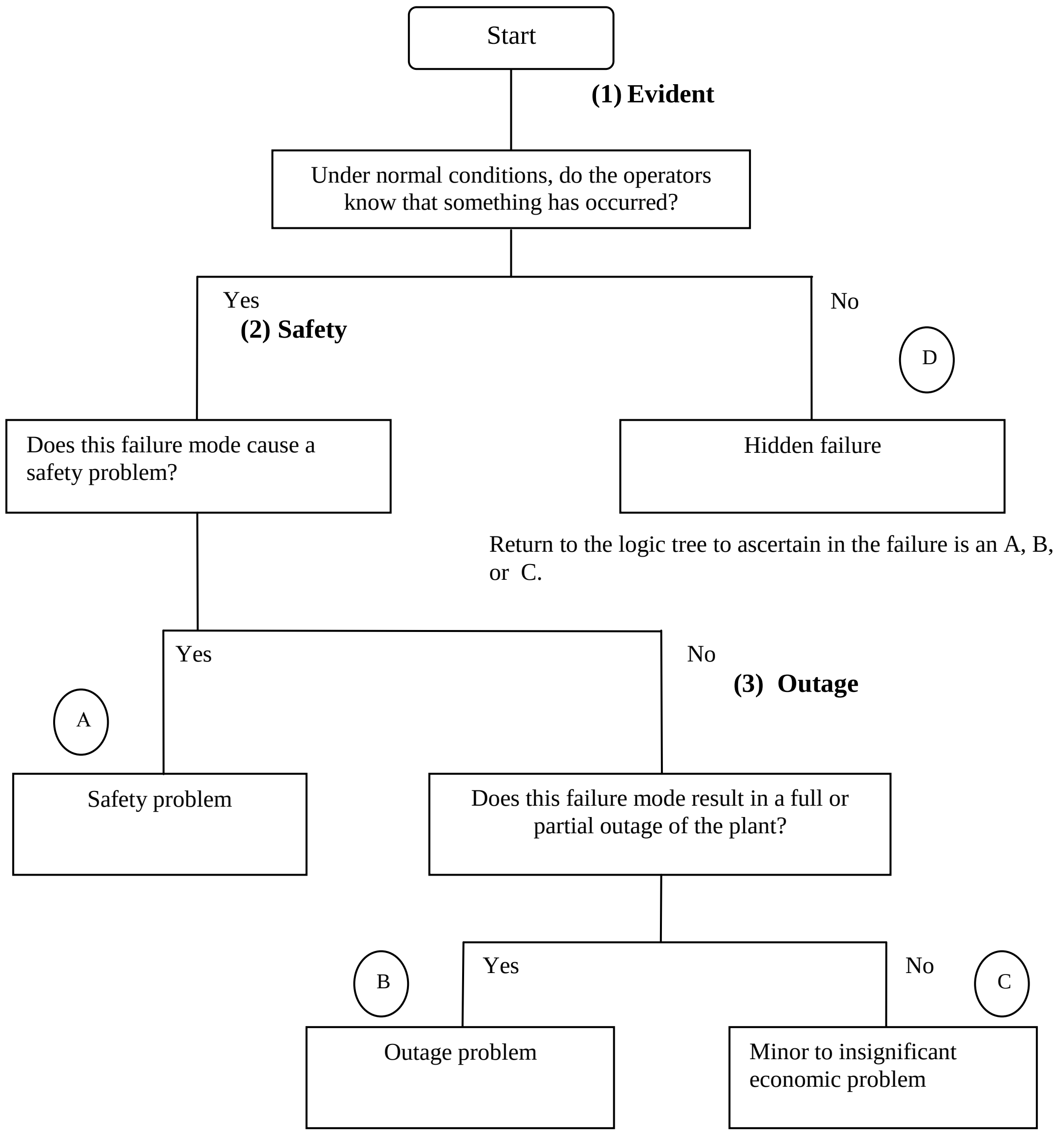
By systematic monitoring of the failure of elements and forming of a database, a basis for the application of the FMECA process is created. In this way one can reach the necessary conclusions for the enactment of corrective measures to remedy the detected deficiencies. Existing standards relating to the FMEA method are different from each other. The differences are, depending of the standards, more or less expressed. Frequently it comes to the form for documenting of FMEA, terminology, labeling of certain values and so on.

3. RISK PRIORITY NUMBER

In accordance with the above mentioned all potential failure modes should be quantified against the possibility of failure, significance of the consequences and appropriated measures for verification of the potential causes of failure. The evaluation is done through the factors of the risk of failure R_1, consequences of failure R_2, and nondetection of the cause of failure R_3, based on expert assessments of people from the FMEA team.

The values of the risk factors are usually ranked by number in the interval of 1. At the risk factor of failure R1, and severity of consequence R2, smaller numbers indicate a lesser and larger numbers greater probability of failure, i.e. severity of consequences of failure. With factor of nondetection of the cause of failure R_3, smaller numbers correspond to larger and larger numbers to smaller possibility to detect the failure. If the description of the established situation is between two values on the scale, as a choice of risk factor it is recommended to adopt higher value. The probability of failure (Probability of Failure - PF) in the exploitation of technical systems is the probability that the suitable potential cause of failure will result in a failure of components or the system. Existence of a failure cause by itself does not mean the automatic occurrence of the failure.

The probability of failure is measured by factor of the occurrence of failure R_1, based on the adopted qualitative and quantitative criteria. Depending on the frequency of failure in the literature there are recommendations for the values of risk factor R_1, [4].



Fifure 1. Logic tree analysis structure

Severity of the consequences of failure (Failure Demerit Value - FDV) is a measure of the impact of potential failure modes of components of the considered system on the working capacity of the system, the user and/or surroundings . While considering the significance of the results of failure, the violation of binding legislation must be taken into consideration. The consequences of failure are usually described by the effects on the user of the technical system. Risk factor values of consequences occurrence R2, are obtained through the analysis of a number of works in this field, by taking the specificity relating to the maintenance-oriented approach for reliability. For each technical system in which FMEA analysis is conducted it is necessary to establish its own criteria, by adhering some general principles [4].

The probability of discovering the causes of failure (Probability of Failure Remedy - PFR) is an estimate of the ability to check the technical systems, detection of the potential disadvantages before the system is put into operation (risk factor R_3).

By identifying characteristics of technical systems and quantitative assessment of factor occurrence, the consequences and nondetection of the failure cause, with the risk priority number - R (Risk Priority Number - RPN), the identification of the weak and risky places of the system is enabled. Risk priority number for all causes of potential failure modes is obtained by multiplying the value of the risk of failure factor R_1, occurrence of the failure consequences R_2, and nondetected failure causes R_3. Value of R, defined in this way, shows the relative priority of importance of individual causes of failure. Based on the above, the risk priority number of *k* cause of *j* failure mode of *i* element of each pair of the causes of failure – failure, is calculated using the equation:

$$R(i,j,k)= R_1(i,j) \cdot R_2(i,j) \cdot R_3(i,j,k) \qquad (1)$$

where:

R1(i,j) – value of the risk of occurrence

R2(i,j) – value of risk factor of failure consequences

R3(i,j,k) – value of the risk factor for nondetection of causes of failure mode of element

In this way, the calculated R values of risk factors are compared with critical values of R_{krit}, determined in common consent by the FMEA team by using table 1 [4].

Table 2 Overall risk rating

S.No.	Mark	Total risk R
1.	Low	1÷50
2.	Medium	50÷100
3.	High	100÷200
4.	Critical	200÷1000

If the individual values of all the causes of failure modes of components are $R < R_{krit}$, the discussed solution is rated satisfactory. Otherwise, for all potential causes of failure modes, whose values are $R > R_{krit}$, it is necessary to propose and implement appropriate preventive and corrective measures to reduce the value of some or all of the risk factors R_1, R_2, and R_3. In defining and implementing these measures, priority should be given to component failure modes and their causes with the highest value of R.

3.1 Risk Priority Number in RCM

The methodology for determining the risk priority index which is given in the Section 3, relates primarily to FMECA in the phase of designing and production of technical systems. Since RCM is actually FMECA in operation of technical systems, the same methodology as in the FMECA can be adopted for determining the risk priority number in RCM analysis. Since it is a phase of exploitation of technical means, the value of the risk factors of nondetection of causes of failure modes of element R_3 is much smaller than in the stages of designing and production. Therefore, a risk factor R3 in the equation (1) can be neglected. [1]

$$R(i,j,k)= R_1(i,j) \cdot R_2(i,j) \qquad (2)$$

where:

$R_1(i,j)$ – value of the risk of failure (failure rate)

$R_2(i,j)$ – value of risk factor of consequence occurrence

Given the above, the criticality of any failure mode in RCM analysis can be written as:

$$K = F \cdot (B + Z + Q + T) \qquad (3)$$

Where:

K – Criticality of failure mode; F - Frequency of failure mode; B – Safety; Z – Standstill; Q – Quality; T - Total costs

Table 2 Assessment of frequency

Frequency	F
Daily	10
Weekly	9
Monthly	8
At intervals of 1 to 12 months	7
Yearly	6
At intervals of 1 to 5 years	5
At intervals of 5 to 10 years	4
Rarely, for example, 1 x in 10 years	1

Table 3 Values of risk factors of consequence occurrence

Consequences	Risk factor

Safety (B)	
Casualties	20
Disability	18
Severe injuries	14
Minor injuries	6
No injuries	0
Standstill (Z)	
Standstill ≥ 7 days	10
Standstill 3 to 7 days	9
Standstill 1 to 3 days	8
Standstill 1 day	7
25% of capacity	6
50% of capacity	4
75% of capacity	2
Without influence	0
Quality (Q)	
Completely unacceptable	10
Acceptable - improvement needed	5
Without influence	0
Total Costs (T)	
Costs ≥ 5000 EUR	10
Costs 1250÷5000 EUR	8
Costs 500÷1250 EUR	6
Costs 250÷500 EUR	4
Costs 100÷250 EUR	2
Costs < 100 EUR	1

Factor of frequency of failure mode F, is among the risk factors R1, and other factors (B, Z, Q, T) belong to the group of factors of occurrence of failure consequence risk R_2.

4. DETERMINING THE CRITICALITY OF FAILURE ON THE EXAMPLE OF PUMP STATION

Water from the well is pumped using two centrifugal pumps that are installed on a pedestal and connected for parallel operation on a common pressure and suction line.

As a drive pumps use the standard three-phase asynchronous motors. With the pump with controlled flow, control work is performed by microprocessor of frequent controller.

Chlorination system is designed to ensure that the chlorinated installation is under vacuum, i.e. that the lower part of the installation is under gage pressure.

Notice for failure m ode according to Equation(3) can be determined by RPN. Critical component is defined as the sum of all RPN failure related to the component.

Table 4 shows the ranking of states according to the cancellation RPN.

Table 4

Failure mode #	**Failure Mode**	**Component**	**Category of the FM**	**RPN**
1.34.01	chlorine leak at the entrance to the vacuum regulator	Vacuum regulator	A	195
1.35.01	chlorine leak on the chlorine valve	Valve for chlorine	A	195
1.33.02	partially interrupted flow of chlorine	Vacuum hose	B	192
1.39.02	dirty or clogged filter	Free chlorine analyer	C	168
1.07.08	distorted pump shaft	Centrifugal pump	B	135
…	…	…	…	…

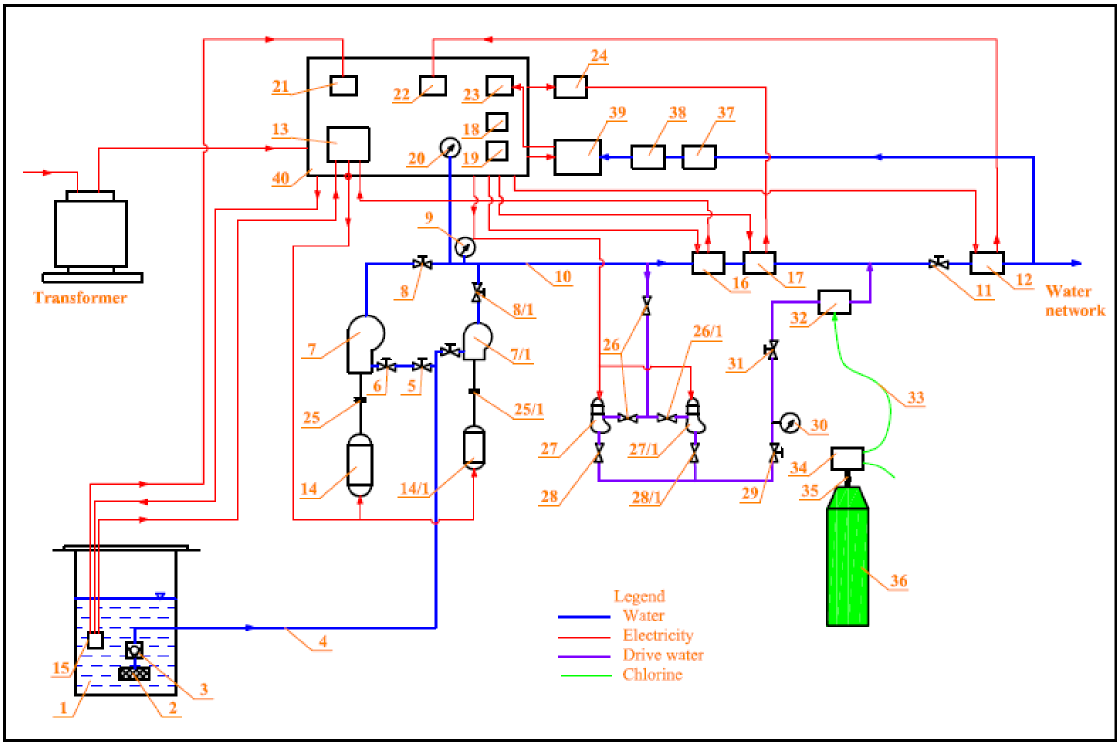


Fig. 2. *Pump station for water supply*

Pumping station consists of the following basic components(Figure2):
1 - well, 2 – suction chamber, 3 - irreversible valve, 4 - suction pipeline, 5 - valve on the suction branch, 6-tap of the pipeline for filling; 7-centrifugal pump, 8-valve on the pressure pipeline, 9-pressure gauge, 10 pressure pipeline, 11-valve V2, 12-flow meter, 13-frequent regulator, 14-motor, 15-hydrostatic level sensor, 16-pressure transducer, 17-flow transducer, 18-switch with indicator of centrifugal pump; 19 - switch with indicator for booster pump operation, 20-sensor for pressure in the pressure pipeline, 21-sensor for water level in the well; 22-sensor of flow in the pressure pipeline, 23- sensor of chloral level 24- flow indicator; 25-connector, 26-gate valve ; 27-booster pump, 28-valve Z3, 29-valve on the pressure branch of the water flow, 30-gauge of water flow, 31 - valve V3, 32-injector, 33-vacuum hose, 34-vacuum regulator, 35-valve for chlorine ; 36-bottles for chlorine; 37-flow regulator of chlorine analyzer; 38 - pressure regulator of chlorine analyzer; 39-analyzer of free chlorine, 40-distribution cabinet.

Critical components of the pumping station is given in Table 5.

Table 5

Component #	**Component**	**Criticality K**
1.14	Electromotor	1404
1.34	Vacuum regulator	970
1.07	Centrifugal pump	967
1.39	Free chlorine analyer	497
1.32	Injector	486
…	…	…

The number of components to the overall risk assessment is shown in Table 6.

Table 6.

S.No.	Mark	Number of components
1.	Low	10
2.	Medium	10
3.	High	9
4.	Critical	11

5. CONCLUSION

By identifying characteristics of technical systems and quantitative assessment of factors of occurrence, the consequences and nondetection of the cause of failure, with the risk priority index - R (Risk Priority Number - RPN), the identification of the weak and the risky places in the system is enabled.

Criticality rating islogical continuation of the RCM analysis. The proposed modified method for determining the critical components of technical systems is easy to apply in the RCM methodology.

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