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CONTENTS

SESSION 7. ENVIRONMENTAL MANAGEMENT AND OCCUPATIONAL SAFETY

RISK BASED MAINTENANCE STRATEGY SELECTION

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Abstract: This paper presents decision-making model for maintenance strategy selection. Problem of right maintenance strategy selection is one of the most important problem in manufacturing enterprises, process industries or enterprises where failure of equipment has major impact on production flow, people, environment or business costs. Presented decision making model for maintenance strategy selection takes into account risk exposure to mechanical equipment failure, business costs, people health and environmental safety. At the other hand each strategy options has its benefits expressed by cost savings. This decision making model for maintenance strategy selection try to optimize between these opposite influential criteria.
Key words: maintenance strategy, decision-making process, risk matrix.

INTRODUCTION

Most often choosing right strategy is decision based on cost-benefit analysis. Benefits are measured in cost savings, maintenance time savings, maintenance material savings, and all maintenance resources savings and not less important – reliability mechanical equipment keeping on desired level. Some strategy options has aim to increase reliability of mechanical equipment but it leads to overmaintenace. So optimal maintenance strategy presents balance between corrective and preventive activity in accordance with business processes [1]. Historically main maintenance strategy differed on: failure replacement, periodical inspection, age replacement, risk-based inspection, continuous monitoring strategies, etc. developed in four basic types of maintenance philosophies: corrective maintenance, preventive maintenance, risk-based maintenance, condition-based maintenance. Nguyen[2] shows that replacement decision nowadays is more complex because decision maker often must decide which available technology on the market to choose for replacement of the current asset. Rapid technological development involve in maintenance decision making process one new aspect in replacement with technologically better solutions compatible with current assets.
Ierace and Cavalieri [3] noticed that in the literature, there was insufficient attention been paid to formulation of a methodological framework for selecting suitable techniques for maintenance strategy selection. They says that the framework should takes into account the organizational competencies with respect to applying the specific risk assessment technique. In such concept of developing methodological framework for maintenance strategy selection, chances of success increase.
In literature, lot of method and techniques was used for solving problem of maintenance strategy selection: AHP, FAHAP, ANP[4], TOPSIS, FME, FTA, ES, etc. Also, number and type of influential criteria for comparing alternative maintenance strategy option vary. In this paper is presented combined approach to maintenance strategy selection, using 4 types of risk matrix for each maintenance strategy option evaluation, and decision support system based on analytic hierarchy process for ranking maintenance strategy options by priorization influential criteria.

CASE STUDY

In this Case study we observed one manufacturing enterprise which is considering three maintenance strategy options. First strategy (STM1-Strategy Maintenance option 1) characteristics are estimated using qualitative risk exposure matrix and this strategy options present current strategy, shown on Figure 1.

Risk Exposure (E)					
Probability (P)	E=P*I				
Very High (>0.7)	MEDIUM	MEDIUM	HIGH	HIGH	HIGH
High (<0.7)	LOW	MEDIUM	MEDIUM	HIGH	HIGH
Medium (<0.5)	LOW	MEDIUM	MEDIUM	HIGH	HIGH
Low (<0.3)	LOW	LOW	MEDIUM	MEDIUM	HIGH
Very low (<0.1)	LOW	LOW	LOW	LOW	MEDIUM
Increases development time	<1%	<5%	<10%	<15%	>15%
	Impact (I)				

Figure 1. Qualitative assessment risk exposure matrix

Using qualitative risk exposure matrix shown on figure 1, risk exposure for STM1 for equipment failure is estimated based on corporate memory and expert opinion, on figure 2. The analysis is conducted for four equipment assets.

Risk Exposure Matrix for STM1					
Probability (P)	Impact				
Very High					
High		3			
Medium		1 2			
Low			4		
Very low					
	Very Low	Low	Medium	High	Very High
	Impact on equipment failure (I)				

Figure 2. Risk exposure matrix for STM1 equipment failure

For same probability of equipment failure, shown on figure 1, next risk matrix shows its impacts on business costs. Figure 2 shows that failure has different significance form aspects of business costs.

Risk Exposure Matrix for STM1					
Probability (P)	*Impact				
Very High					
High		3			
Medium		1	2		
Low			4		
Very low					
	Very Low	Low	Medium	High	Very High
	Impact on business costs (I)				

Figure 3. Risk exposure matrix for STM1 business costs

Also, for same probability of equipment failure, shown on figure 1, next risk matrix shows its impacts on people. Figure 4 shows that failure of equipment assets no. 1 has high on people and also on environment, figure 5. Equipment 5 is a reservoir under pressure containing compressed natural gas.

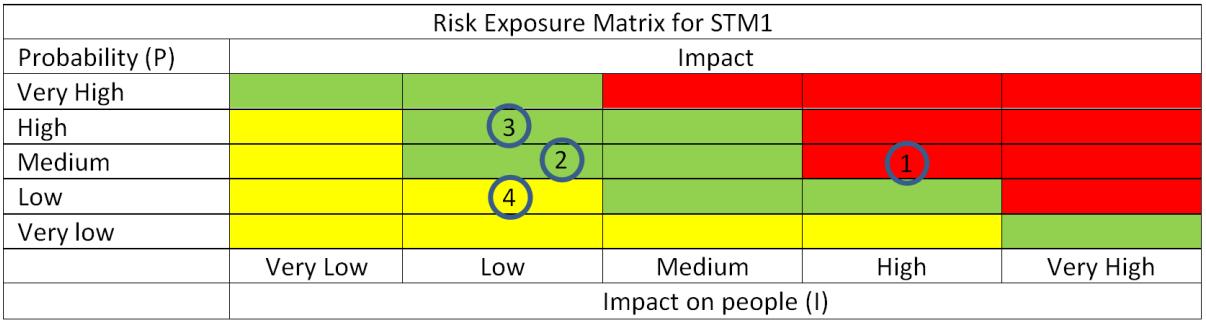

Figure 4. Risk exposure matrix for STM1 people

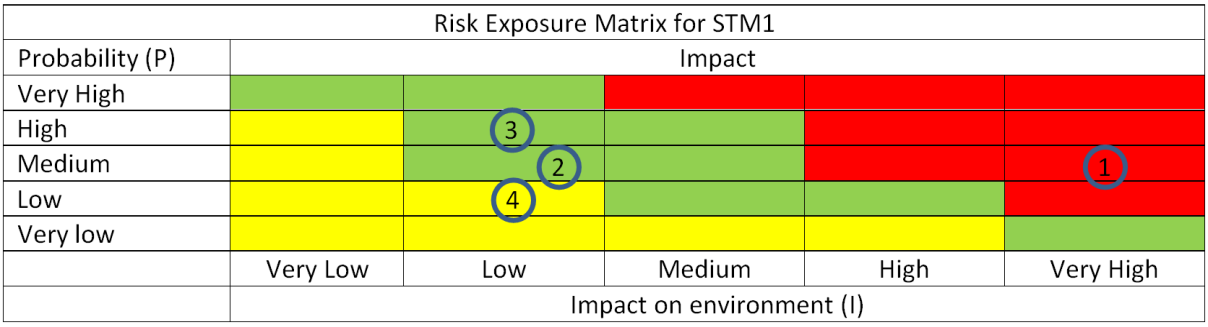

Figure 5. Risk exposure matrix for STM1 environment

All four risk exposure matrix are performed for strategy 2 (STM2) and strategy 3 (STM3) option and for observed equipment, total costs are calculated: preventive maintenance, corrective maintenance, lubrication as specific PM task, contracted preventive and corrective maintenance, inspection costs, replacement costs, ‘’non-working’’ maintenance (safety, meetings), supervision, planning, lubricants, capital improvements, etc. Maintenance costs are shown in table 1.

Table 1. Maintenance costs for STM1, STM2 and STM3

	STM1	STM2	STM3
Total maintenance costs (in thousands of RSD) /per year	152000	142500	124500
Percent (%)	100	93.75	81.90789
Cost savings (%)	0	6.25	18.08

STM1 has the biggest total maintenance costs, so if this is a referent value, STM2 has 6,25 % cost savings, and STM3 has 18,08% cost savings.

DECISION SUPPORT TOOL

In this section decision support tool was used for evaluation each strategy options. Very important issue in design decision making model framework is to compare different measurement units in same decision model: different risk exposure and costs savings for each strategy options. In this sense we use weights for influence criteria. In the next table is shown decision making matrix.

Table 2. Decision making matrix

	R - FAILURE	R - BUSINESS	R- PEOPLE	R- ENVIRONMENT	COST SAVINGS
WEIGHTS	Critical	Very Important	Critical	Critical	Very Important
STM1	MEDIUM	MEDIUM	HIGH	HIGH	0
STM2	MEDIUM	LOW	MEDIUM	MEDIUM	6,25
STM3	MEDIUM	MEDIUM	HIGH	HIGH	18,08

Verbal scale for weights of influence criteria is five-stages (Critical – 100%, Very important – 75%, Important – 50%, Unimportant – 25%, Trivial - 0%), while verbal scale for risk exposure is three-stages (High – 100%. Medium - 50%, Low - 0%). Using results from case study for specific enterprises, by monitoring 4 equipment assets, and determining its positions in risk exposure matrix (fig.1,2,3,4 for strategy maintenance option 1 is shown in this paper), further research was continuing by determining overall qualitative evaluation. So, for STM1, overall evaluation for "R-failure" matrix is "medium"; overall evaluation for "R-business" overall evaluation is "medium"; for "R-people" overall evaluation is "high"; for "R-environment" overall evaluation is "high" and for "cost savings" overall evaluation is zero. This overall conclusion was made by observing areas in risk matrix where equipment assess belong. The similar procedure was conducted for second and third maintenance strategy option, and a final result is given in table 2.
Using analytical hierarchy process as one of the method for decision making for optimal maintenance strategy [5,6,7], results are obtained, table 3.

Table 3. Calculating priorities for different strategy option

Goal	Weights	Priorities	Rating Set	Attributes	STM1 Rating	STM1 Priority	STM2 Rating	STM2 Priority	STM3 Rating	STM3 Priority
Goal	100,00	0,222	Rf	Rf	50,00	0,500	50,00	0,500	50,00	0,500
	75,00	0,167	Rb	Rb	50,00	0,500	100,00	1,000	50,00	0,500
	100,00	0,222	Rp	Rp	0,00	0,000	50,00	0,500	0,00	0,000
	100,00	0,222	Rr	Rr	0,00	0,000	50,00	0,500	0,00	0,000
	75,00	0,167	Cost Savings	Cost Savings	0,00	0,000	6,00	0,333	18,00	1,000

Table 4 shows ranking maintenance strategy options. Strategy STM2 present the best alternative in this enterprise.

Table 4. Ranking alternatives

LOWEST LEVEL	STM3	STM2	STM1	MODEL WEIGHTS
Re	0,000	0,500	0,000	0,222
Rp	0,000	0,500	0,000	0,222
Rb	0,500	1,000	0,500	0,167
Rf	0,500	0,500	0,500	0,222
Cost Savings	1,000	0,333	0,000	0,167
Results	0,361	0,556	0,194	

Although STM3 has the most significant cost savings, its risk exposure for people and environment is high. STM1 also has high evaluation mark in risk matrix for people and environment and has no cost savings, so STM1 is the worst strategy option. STM2 has moderate risk exposure for people, failure and environment (which are the critical influential criteria's) and has 6,25% cost saving comparing to current maintenance strategy, which make this strategy option the best solution in this study case.

CONCLUSION

In this paper the decision model for maintenance strategy selection is presented. Concept of decision making model involves all risk exposure aspects: risk exposure matrix for equipment failure, risk exposure matrix for business losses (measured by costs), risk exposure for people, risk exposure on environment and in model are involved benefits of each strategy options expressed through cost savings. Decision making model for maintenance strategy selection uses weights of influential criteria and calculate significance each alternative according to priority. Presented decision making-model for strategy selection can be used in different manufacturing enterprises, simple procedure make it easy for application by decision makers on all managerial levels. Presented model gives better review of advantages or disadvantages of several maintenance strategy option then traditional cost benefit models. Risk exposure to all aspects by using this methodology can be observed together with potential cost savings.

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