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MAINTENANCE PROCESS GOALS ASSESSMENT IN SMALL AND MEDIUM ENTERPRISE: A FUZZY APPROACH

Abstract: *Today, business and production systems have become much less tolerant on the issue of production equipment failures. This brings intense pressure and expectations of the maintenance function as significantly broadening the equipment that is necessary to include the advanced maintenance program with a clear trend setting concept of "zero failure" as a realistic and achievable goal. As a mandatory demand of ISO 9001 standard, process improvement must be continual. This paper presents a new fuzzy model for maintenance process goals assessment which is main input for defining process improvement strategy.*

Keywords: *Proactive maintenance, Fuzzy sets, Process goals*

1. INTRODUCTION

The characteristics of business environment had significant changes at the end of the 20th and beginning of the 21st century. The current global political and economic trends, effects of changes in the markets of goods and capital, the increase in prices of raw materials and energy have led most companies, particularly those in manufacture sector, in the situation to their survival and future depends, above all, of the features and speed of adjustment to the new situation and conditions.

Today, flexibility and adaptability of business strategy and willingness to radically redefine and adapt to the environment is a feature that separates successful and unsuccessful companies, those that recorded a growth of production and profits, winning new markets and expansion of influence in relation to those that have stagnated or are often forced to operate in a recessive fashion, or even completely stop their activities. This requirement is imperative in any production and business systems, regardless of its size and influence.

Properly defined and implemented business strategy in all aspects of a production/business system is a strategic framework that includes implementing further detailed analysis of needs and opportunities and defines appropriate approaches and strategies in organization and management of each individual business segment. This discussion relates primarily to production-oriented systems, it is clear that production and supported functions have a dominant importance.

Maintenance of production equipment and technical systems in general is an important element that can have a significant positive but often highly negative impact on the parameters and indicators that define the success of production systems [1]. In this sense, the relationship between business strategy and the strategy of maintaining in a production/business system is very clearly expressed and reflected in a number of common factors and relationships are equally spaced vertically and horizontally [1]. A clear trend of acceptance and an

intense need for significant redefinition of maintenance strategy began significantly earlier and progressive swing gains in the eighties of the last century, when new maintenance concepts shown with the simultaneous penetration of the Japanese maintenance philosophy and production in general to the West [2].

Modern maintenance strategy of technical systems in production systems, based on a comprehensive implementation of preventive measures in daily practice, with the basic need and an expectation that the reliability and availability of production equipment will be increased in proportion to the efforts and activities that are conducted through implemented maintenance program. Quantification of the improvement is realized through the analysis of standardized group of economic and technical indicators, which are mainly related to the extension of time in work and reducing the time of failure and their frequency [3]. Certainly, a significant increase in the values of these parameters can be achieved by modifying production equipment and components, or installing more reliable, more permanent solution, but we need to make sure that we exhausted all possibilities in this respect is the existing equipment and components. Right there is located the main task and expectation that defined maintenance strategy should answer and refers to the need to extend the existing equipment lifecycle while increasing reliability and availability to the limits [4]. That means that technical system besides performing its actual function has another equally important task how that function is performed.

The primary response to these requests is reflected in the replacement of the time-based preventive maintenance activities, with activities which are based on identification of system status and diagnostics of possible failures. These activities allow monitoring of a trend of degradation or exploitation of selected diagnostic parameter of the system or component and generate a range of new data that can be used to predict equipment failure and take appropriate action. This is particularly important when it comes to sophisticated, highly productive technical systems whose role in the production systems is indispensable [5].

The crucial question is how to respond to all demands of production and business systems and what solution will satisfy most of their needs and which will be presented with an optimal organizational and management maintenance model [6]. There are various types of maintenance [7] but in our case we will use the most contemporary type of maintenance known as proactive maintenance. Proactive maintenance setting up the goal that failure of a part or the whole system does not occur, or to provide such conditions of exploitation, which will guarantee unlimited lifetime of a technical system [8], [9], [10].

With this in mind it is clear that proactive approach will be the key concepts in the field of maintenance in the future.

In general, the importance of each business goal depends on multiple factors, such as the type of economic activity, enterprise size, and others. It can be assumed that the relative importance of maintenance process goals at the enterprise level have different relative importance. Weight value of business goals are almost unchanged during a predefined period of time and involve a high degree of subjective assessment of the management team. In this paper, the weight of maintenance process goals are given by a matrix pairs of comparison the relative importance of maintenance process goals (analogous to the AHP method). It is believed that this approach is closest to the human way of thinking.

In this paper, values of maintenance process goals are described for every period of time by fuzzy rating of

management team. Their judgments are expressed by predefined linguistic expressions.

In this paper, uncertainty in relative importance of maintenance process goals and values of maintenance process goals for each considered period are modeled by fuzzy sets [11] [12] [13]. Fuzzy set theory can provide a valuable framework for handling imprecise and ambiguous data, and provides reasoning and decision making methods based on such data. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions [14].

The main contribution of this paper can be presented as introduction of structured fuzzy mathematical model for performance assessment of maintenance process goals at the enterprise level.

2. MODEL FOR MAINTENANCE PROCESS GOALS ASSESSMENT IN SMEs

In theory and in practice there are different approaches in process division. Process classification framework covers four divisions of master processes [15]: (1) management, (2) management of resources, (3) implementation and (4) measurement, analysis and improvement. Besides this classification there is basic division [16]:

- Management processes,
- Main processes and
- Support processes.

From the aspect of value creation, the processes are divided into key processes and support processes, which involves the management process. All selected organizational processes must meet the selection criteria, relating to the relevance of the market potential for improvement. Regardless of how the division process in the enterprise is made, maintenance is a very important process.

According to the ISO 9001 demands, defined processes in organization must be treated in a way of continual improvement. That can be achieved through the assessment of process goals. After assessment, management has necessary input for defining strategy for process improvement. In the table 1 is presented the model for maintenance process performance assessment consisted from 3 goals.

Table 1 – Model for maintenance process goals assessment in SMEs

Maintenance process goals		**Goal1**	**Goal2**	**Goal3**
Monthly indicators values	**1**	4	5	6
	2	5	4	7
	3	5	5	6
	4	6	6	5
	5	7	6	7
	6	7	7	6
	7	6	7	7
	8	7	7	7
	9	7	6	7
	10	6	6	6
	11	6	5	5
	12	5	4	6

These goals represent three of the most important factors which are from the view of management team necessary to determine maintenance process assessment:

- MTBF - Mean Time Between Failures (G1),
- MTTR – Mean Time To Repair (G2) and
- MPR - Maintenance Plan Realization (G3).

MTBF (h) is average time between inherent failures of a system during operation MTBF can be calculated as net operating time divided with number of failures [17] [18]. MTTR (h) is average time to spend for failure elimination of component and can be calculated as total time in failure divided with number of failures [18]. MPR (%) represents percentage success of planned maintenance activities. MTBF and MPR

need to be higher value, while MTTR needs to be the lowest as much as possible.

Maintenance process ensures that the monthly, quarterly, semiannual and annual form a document that provides necessary data for the quantification process. Tables from 2 to 4 represent accepted values for mentioned characteristics.

Table 2 - MTBF

MTBF (h)	< 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	> 100
G1	1	2	3	4	5	6	7

Table 3 – MTTR

MTTR (h)	< 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	> 100
G2	7	6	5	4	3	2	1

Table 4 – MPR

MPR (%)	< 70	70 - 75	75 - 80	80 - 85	85 - 90	90 - 95	95 - 100
G3	1	2	3	4	5	6	7

Legend: 7 is the highest and the best mark, 1 is the lowest and the worst.

3. FUZZY MODELLING

3.1 The relative importance of goals of maintenance process

Management team determines the number and kind of criteria primarily depending on the type of industry and size of considered industrial organization.

All the criteria for maintenance process goals evaluation are usually not of the same relative importance. Also, they can be considered as unchangeable during the considered period of time. They involve a high degree of subjective judgment and individual preferences of decision makers. We think that the judgment of each pair of treated criteria best suits human-decision nature (by analogy with AHP method [19]. In conventional AHP, the pairwise comparison is established using a standard integer scale. The use of discrete scale of AHP is simple and easy, but it is not sufficient to take into account the uncertainty associated with the mapping of one's perception to a number (18,-SCI). Decision makers express their judgments far better by using linguistic expressions than by representing them in terms of precise numbers.

In this paper, it is assumed that the linguistic expressions are modeled using triangular fuzzy numbers defined in interval from 1 to 5, where 1 denote as the lowest relative importance and 5 denotes the highest relative importance:

- *low importance* - $\tilde{R}_1 = (x;1,1,4)$
- *medium importance* - $\tilde{R}_2 = (x;1,3,5)$
- *high importance* - $\tilde{R}_3 = (2,5,5)$

The relative importance of criterion k compared to the criterion k',k,k'=1,…,K, is described by one of five predefined linguistic expressions which are modeled by fuzzy triangular number $\tilde{w}_{kk'}$. The highest and the lowest limit of these fuzzy numbers is highlighted as $1_{kk'}$, $u_{kk'}$, and modal value is $m_{kk'}$.

If the relative importance of criterion k' compared to the criterion k is significantly greater then the value of element in the pairs matrix of process comparison must be presented by fuzzy triangular number:

$$\tilde{w}_{kk'} = \left(\frac{1}{u_{kk'}}, \frac{1}{m_{kk'}}, \frac{1}{l_{kk'}} \right)$$

If the importance of the matrix elements described above are equal, it can be represented by a single point whose value is 1 and which is represented by triangular fuzzy number (1,1,1).

3.2 Fuzzy rating of values of maintenance process goals

The each considered goal k, k=1,..,K on the month level m, m=1,..,12 in any enterprise involve subjective judgments of and individual preferences of each decision maker of management team.

In this paper the SMEs are in the focus so it can be assumed that decision makers of management team can be made decisions by consensus.

It is closer to human reasoning if decision makers express their opinions and evaluations by using linguistic expressions rather than numeric values. In this paper, fuzzy rating of management team is expressed by predefined linguistic expressions, which are modeled by triangular fuzzy numbers,

$$\tilde{v}_{km},\ k=1,..,K;m=1,..12$$

The lowest and the highest limit of this modal value of triangular fuzzy number $\tilde{v}_{km}$ are set as L_{km}, U_{km}, M_{km}, respectively.

The values in the fuzzy triangular domain, $\tilde{v}_{km}$ belongs to the interval from 1 to 9 and they have the same meaning and values as a standard scale which is defined by AHP [19].

In this paper, we use five linguistic expressions for describing the fuzzy rating of indicators value, which are defined by triangular fuzzy numbers in the following way:

- *very low value – (y;1,1,2)*
- *low value – (y;1.5,3,4.5)*
- *medium value – (y;3,5,7)*
- *high value – (y;5,7,9)*
- *very high value –* (y;8,9,9)

3.3. The proposed fuzzy algorithm

The proposed fuzzy model is realized in the following steps:

Step 1. Setting the matrix pair of comparing the relative importance of maintenance process goals

$$\left[\tilde{w}_{kk'}\right],\ k,k'=1,..,K$$

Weights vector of the considered criteria is calculated by applying the concept of extent analysis. The weights vector is represented as:

$$W_p=\left(\left(\mathrm{Bel}\left(\tilde{S}_k\right)\right)\right),k=1,..,K$$

Where $\mathrm{Bel}\left(\tilde{S}_k\right)$ is measure of belief according to which triangular fuzzy number $\tilde{S}_k$ is bigger than all other triangular fuzzy numbers $\tilde{S}_{k'}$, k,k'=1,…,K;k≠k'. This value is obtained by applying the method for fuzzy numbers comparison [20] [21].

After normalizing W_P, we get the normalized weights vector W:

$$W=(w_1,\ldots,w_k,\ldots,w_K)$$

It is a non-fuzzy number and this gives the priority weights of one criterion over the other.

Step 2. In general, the parameters can have cost and benefit nature. The value of every parameter can be described through the fuzzy number $\tilde{v}_{km}$ by management team. Applying the normalization process, domain of the triangular fuzzy numbers, $\tilde{v}_{km}$ are mapped into a set of real numbers on the interval from 0 to 1 and in that way they are becoming comparable, $\tilde{r}_{km}=(z;a_{km},b_{km},c_{km})$. The value 0, and the value 1 denote that value of maintenance process goal k, k=1,..,K on the level of month m, has the lowest or the highest value, respectively. In this paper, a linear normalization procedure is applied [22].

Step 3. Calculating weighted value of maintenance process goal k, on level of each month m, m=1,…,12,

$$\tilde{d}_{km} = w_k \cdot \tilde{r}_{km}$$

Step 4. We need to calculate value of maintenance process goal k, k=1,.,K annually:

$$\tilde{D}_k = \frac{1}{12} \cdot \sum_{m=1}^{12} \tilde{d}_{km}$$

Step 5. Calculate performance of monthly maintenance process with respect to all treated goals and its weights:

$$\tilde{PM}_m = \frac{1}{K} \sum_{k=1}^{K} \tilde{d}_{km}$$

Step 6. We need to rank performance of maintenance process by using method which is developed in [20] [21].

Step 7. Calculate performance of maintenance process of considered enterprise annually.

$$\tilde{PM} = \sum_{m=1}^{12} \tilde{PM}_m$$

4. ILLUSTRATIVE EXAMPLE

The selected enterprise for model testing belongs to the SME of production sector. The relevance of this type of enterprise can be illustrated through the data of Republic Statistical Office of Serbia: (1) 99.4% of all enterprises belong to SMP in 2010, and (2) the most of employees work in the production sector of industry. From the perspective of joining EU, SMEs are very important for Serbian economy. Relative importance of maintenance goals is presented by matrix:

$$\begin{bmatrix} 1,1,1 & \tilde{R}_3 & \tilde{R}_2 \\ 1/\tilde{R}_3 & 1,1,1 & \tilde{R}_1 \\ 1/\tilde{R}_2 & 1/\tilde{R}_1 & 1,1,1 \end{bmatrix}$$

By using the proposed fuzzy algorithm weights vector is determined:

W_P=(1,0.506,0.275)

After normalization the weight vector is:

W=(0.561,0.284,0.154)

In Table 5 input data of values of monthly maintenance goals are presented:

Table 5 – Monthly performance values and their rank of maintenance goal performance

	k=1	**k=2**	**k=3**
m=1	*medium value*	*high value*	*high value*
m=2	*medium value*	*medium value*	*very high value*
m=3	*medium value*	*medium value*	*high value*
m=4	*high value*	*high value*	*medium value*
m=5	*very high value*	*high value*	*very high value*
m=6	*very high value*	*very high value*	*high value*
m=7	*high value*	*very high value*	*very high value*
m=8	*very high value*	*very high value*	*very high value*
m=9	*very high value*	*high value*	*very high value*
m=10	*high value*	*high value*	*high value*
m=11	*high value*	*medium value*	*medium value*
m=12	*medium value*	*medium value*	*high value*

By using Algorithm (from Step 2 to Step 4) the value of goals on the year level is calculated:

$\tilde{D}_1 = (0.332, 0.483, 0.519)$

$\tilde{D}_2 = (0.015, 0.045, 0.067)$

$\tilde{D}_3 = (0.102, 0.129, 0.148)$

Based on the acquired results, the most successful goal of maintenance on the year level is MTBF - Mean Time Between Failures (G1). The lowest level of

maintenance goals is acquired in the case of MPR - Maintenance Plan Realization (G3). In order to improve performances of maintenance process, the first need is to increase the level of third goal achievements. That can be done by Maintenance Plan Realization review and proposing improved plan. All actions that are not needed should be eliminated from this plan which should increase effectivity of Maintenance Plan Realization goal.

By applying the proposed fuzzy Algorithm (Step 5 to Step 6), monthly performance values and monthly rank of maintenance goal performance are determined (Table 6).

Table 6. Rank of maintenance goals indicators

	$\tilde{PM}_m$	**Rank**
m=1	(0.104, 0.164, 0.228)	9
m=2	(0.121, 0.175, 0.228)	8
m=3	(0.104, 0.164, 0.228)	9
m=4	(0.132, 0.188, 0.246)	7
m=5	(0.223, 0.252, 0.257)	1
m=6	(0.206, 0.237, 0.25)	3
m=7	(0.161, 0.208, 0.25)	4
m=8	(0.116, 0.249, 0.25)	2
m=9	(0.223, 0.252, 0.257)	1
m=10	(0.145, 0.199, 0.257)	5
m=11	(0.135, 0.194, 0.258)	6
m=12	(0.009, 0.164, 0.228)	9

According to results in table 2 maintenance processes in considered enterprise has the best performance in 5th and 9th month. The worst performance occurs in 1st, 3rd and 12th month. Enterprise management needs to take and implement actions which will lead to the improvement of maintenance process performance. This would be possible by applying procedures which is defined in step 7 of proposed algorithm. Also, we can calculate total value of maintenance process performance:

$$\tilde{PM} = (0.147,\ 0.204,\ 0.245)$$

In general, treated organization has good maintenance process which can be slightly improved. The measures that will lead to this improvement are related to the Maintenance Plan Realization review which is the third maintenance goal.

5. CONCLUSION

The industrial management practice shows that process performances must be analyzed continually. In this paper, a new fuzzy model for evaluation and ranking of maintenance process goals is proposed. The proposed model was tested on a selected medium size enterprise of production sector in Central Serbia. The following conclusion is made: (1) it is possible to describe the considered problem by formal language that enables to look for the solution by exact method, (2) the all uncertainties such as the relative importance of maintenance process goals, are modeled by fuzzy sets theory, (3) the developed fuzzy method give the possibilities through simulation to get the answer if there would be the result change if the input data change, and (4) the illustrated numerical example is given.

The further research will cover the scope of process improvement measures as well as improving overall organizational resilience.

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