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The Assessment of Maintenance Process Vulnerabilities in Small and Medium Enterprises

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Recently, business/production systems have become much less tolerant to production equipment failures. This brings intense pressure and expectations to maintenance function and a necessity to include an advanced maintenance program with a clear trend setting concept of "zero failure" as a realistic and achievable goal. Therefore, organizations worldwide strive towards techniques that will achieve business goals such as improved efficiency, decreased level of risk, increased safety, and sustainable development that separate successful from unsuccessful companies.
One approach that can improve the realization of the maintenance process is detecting process vulnerabilities from the management aspect. This is a very important issue in an SME and it can have a big influence in the matter of its overall resilience. In this paper, a methodology for quantification of vulnerabilities of the maintenance process which represent significant input for decision makers in an organization is presented. The model is tested through an illustrative example in one enterprise from the production sector in Central Serbia. The obtained data can be a powerful input for defining an appropriate business strategy and future steps.

1. Introduction

A significant part of business success is coping with the organizational vulnerabilities which represent the relevant sources of potential for organizational business performance breakdown and may lead to its complete collapse. In literature, management of organizational vulnerabilities is often treated as a part of organizational resilience (McManus, 2007), although resilience is treated in different areas such as supply chain management (Sheffi, 2005), safety engineering (Hollnagel et al., 2006), etc. Resilient entities, in most cases, have the ability to bounce back from disruption to normal condition in a short period of time. The relationship between resilience and vulnerabilities is an open question in many science fields, from environmental change to socio-economical systems. This paper deals with the problem of assessment of maintenance process vulnerabilities in small and medium enterprises (SME). Despite this being one of the most important processes in business/production systems regarding product quality improvement, improved efficiency, safety and sustainability (Waeyenbergh and Pintelon, 2004), maintenance is not considered as an important concept in scientific way (Wang et al., 2007). But the facts show otherwise. Poor maintenance activities have a negative effect on the financial state of enterprises and become one of the biggest costs (Arunraj and Maiti, 2007). Today, this field is becoming more and more interesting for academics, because average maintenance costs are 15-60 % of the total production costs (Mobley, 2002). This only confirms that maintenance is not only a concept where an enterprise loses money, but a concept which is necessary to reach certain, highly rated business targets (Waeyenberg and Pintelon, 2002). Choosing the right maintenance concept and constantly monitoring parameters that impact on the maintenance process has a greater influence on performance (Swanson, 2001).
The process approach is widely accepted in management practice and it can be an appropriate base for business improvement solutions such as organizational resilience, lean production, WCM (Arsovski et al., 2011). The process approach treats a business organization as an interrelated network of its business processes. In theory and in practice, there is no unified process taxonomy and a basic classification (Oakland, 2004) can be presented in the following way: (1) processes of management, (2) the main

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processes and (3) support processes. The maintenance process, which is the focus of this paper, may be seen as a support process. Muchiri et al. (2011) described key steps for successful implementation of a maintenance process. Also, it is mentioned that all indicators need to be identified and classified for the best maintenance results and to achieve the outlined maintenance objectives. One of the significant processes for normal business activities of an organization is the maintenance process. Since modern business demands production assets continuous improvement, a maintenance process needs to be highly resilient in order to accomplish new tasks.

In this paper, uncertainty in parameter values of maintenance indicators and their relative importance are modeled by fuzzy sets (Klir and Folger, 1988, Zimmermann, 2001). Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions (Kaur and Chakrabortyb, 2007). In literature, there are almost no papers which present an assessment of the level of maintenance process vulnerabilities in an exact way. The motivation for using presented approach has emerged from the fact that every single solution based on an exact way is less affected by the subjective view of problems from decision makers and therefore is more accurate. Also, this paper has the intention to propose a model for assessment of maintenance process vulnerabilities in SMEs which should appoint the possibilities for process deviations that may drive away system from its expected normal operating conditions. After analysis of trends in organizational vulnerabilities' research, a description of maintenance process is presented. After that, basic assumptions of the model are presented. These assumptions imply the need for fuzzy ratings of the proposed model's indicators for a quarterly period of time. As a verification of the proposed model, an illustrative example is presented. The contributions of this paper are the following: (1) the level of maintenance process vulnerabilities' problem is stated as a multi-attributive task, (2) it handles all uncertainty of the considered problem using fuzzy sets and (3) the developed algorithm can be used to analyze stability of the rank of maintenance indicators during a determined time period.

2. Modeling of uncertainties

It is assumed that all uncertainty and imprecision of the relative importance of maintenance indicators and parameter values of maintenance indicators are described by a management team. They express their judgments far better by using linguistic expressions than by representing them in terms of precise numbers. In this paper, the used linguistic expressions are modeled by triangular fuzzy numbers. The shape of membership function reflects the degree of tolerance vs. conservatism. Triangular fuzzy numbers are mostly used for modeling of uncertainties in different problems.

2.1 Modeling of the relative importance of maintenance indicators

All the maintenance indicators which impact on the assessed level of maintenance process vulnerabilities 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 management team members. We think that the judgment of each pair of treated maintenance indicators best suits human-decision nature (by analogy with Tadic et al., 2013). The use of the 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. In this paper, the fuzzy rating of the management team is described by linguistic expressions which can be represented as a triangular fuzzy number $\tilde{W}_{ii'} = \left(x; l_{ii'}, m_{ii'}, u_{ii'}\right), i = 1,..,I; i \neq i'$ with the lower and upper bounds $l_{ii'}, u_{ii'}$ and modal value $m_{ii'}$, respectively. These triangular fuzzy numbers are:

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

high importance - $\tilde{R}_4 = (x;3,4,5)$ and *very high importance*- $\tilde{R}_5 = (x;4,5,5)$

The value 1, denotes that maintenance indicator i is as important as maintenance indicator $i', i = 1,..,I; i \neq i'$, and value 5 denotes that maintenance indicator I is much more important than maintenance indicator $i', i = 1,..,I; i \neq i'$.

If the strong relative importance of maintenance indicator i' over maintenance indicator i holds, then a pair-wise comparison scale can be represented by the fuzzy number $\tilde{W}_{ii'} = \left(\tilde{W}_{i'i}\right)^{-1} = \left(\frac{1}{u_{ii'}}, \frac{1}{m_{ii'}}, \frac{1}{l_{ii'}}\right)$.

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

2.2 Modeling of parameter values

In general, the maintenance indicators are presented by set $I=\{1,...,i,...,I\}$ where i is the index for a maintenance indicator and I is the total number of identified maintenance indicators. The indicators of maintenance process vulnerabilities presented in this paper are adapted from McManus (2007) because this set of indicators has a very good correspondence with the selected type of organizations.

Each maintenance indicator is described by using three parameters: exposure, sensitivity and adaptive capacity (Turner II et al., 2003). Parameter values of each identified maintenance indicator are evaluated by the management team which makes decisions by consensus. The linguistic expressions for the describing of parameter values of maintenance indicators are modeled by triangular fuzzy numbers:

very low value - $\tilde{v}_1 = (y;1,1,2.5)$ *low value* - $\tilde{v}_2 = (y;1,3,5)$ *medium value* - $\tilde{v}_3 = (y;2.5,5,7.5)$

large value - $\tilde{v}_4 = (y;5,7,9)$ and *very large value*- $\tilde{v}_5 = (y;7.5,9,9)$.

Domains of these triangular fuzzy numbers are defined in real set numbers into interval [1-9] (by analogy to Satty's measurement scale) (Satty, 1990).

Values: exposure, sensitivity and adaptive capacity of maintenance indicator I, i=1,..,I in time period t, t=1,..,T, are described by triangular fuzzy numbers: $\tilde{v}_{cit}=(l_{cit},m_{cit},u_{cit})$, $\tilde{v}_{pit} = (l_{pit},m_{pit},u_{pit})$ and $\tilde{v}_{sit} = (l_{sit},m_{sit},u_{sit})$, respectively. Lower and upper bounds and modal values of triangular fuzzy numbers $\tilde{v}_{cit}$ $\tilde{v}_{pit}$, $\tilde{v}_{sit}$ are (l_{cit},u_{cit}), (l_{pit},u_{pit}), (l_{sit},u_{sit}) and m_{cit}, m_{pit}, m_{sit}, respectively.

3. The model for assessment of maintenance process vulnerabilities in SMEs

By size, enterprises that enter the scope of this research can be categorized as SMEs of production sector. In these types of enterprises especially, organizational vulnerabilities must be treated permanently because in a time of crisis they may cause failures, unexpected costs, etc. Since there is no unique model for organization vulnerabilities, the proposed model of the paper has a strong connection with social science. Vulnerability is a structurally complex subject, so it cannot be easily reduced to a single metric which makes it hard to quantify. That is why it is very hard to define a unique threshold of risk, danger or harm for an organization. Since there is no clear demarcation of concepts that treats the process vulnerabilities in an organization, this paper propose an ecological conceptual model (Turner II et al., 2003) that is adapted to the needs and characteristics of organizations and their processes. The model is also in compliance with the model presented by McManus (2007) which identifies significant vulnerabilities: (1) planning strategies, (2) participation in exercises, (3) capability and capacity of internal resources, (4) capability and capacity of external resources and (5) organizational connectivity.

The key question in process exposure evaluation is how process vulnerabilities affect the resilience of an entire organization, i.e. how they affect the organization's ability to respond to some disturbances. An assessment of process adaptive capacity needs to find answers how to defined plans and redundant resources should prevent the loss of process function in the case of disturbances. During sensitivity assessment of a process, the management team must analyze how sensitive organization may become if certain vulnerabilities occur. For the management team carrying out the analysis, the following tasks are important: (1) to determine the worst maintenance vulnerability indicator, i^* in time period t, t=1,..,T and (2) to determine the level of maintenance process vulnerabilities in time period t, $\tilde{MPV}_t$, $t = 1,..,T$.

The proposed fuzzy algorithm is formally given as follows:

Step1. Input fuzzy matrix $\tilde{W}$ = $[\tilde{W}_{ii'}]$, $i,i'=1,..,I$. The weight of maintenance indicator i, i=1,..,I is calculated by using the procedure which is in Chang (1996).

Step 2. As the parametric of maintenance indicators can be benefit and cost type, it is necessary to normalize parameter values. Applying the normalization process, the domain of the triangular fuzzy numbers, $\tilde{v}_{cit},\tilde{v}_{pit},\tilde{v}_{sit}$, $i = 1,..,I$ is mapped into a set of real numbers in interval [0-1] and in that way they become comparable. The value 0 and value 1 denote that the treated parameter has the lowest or highest value, respectively. Normalized values of triangular fuzzy numbers are triangular fuzzy numbers, too. In this paper, a linear normalization procedure is applied (Shih, et al, 2007).

These normalized parameter values are denoted as $\tilde{r}_{cit} = (L_{cit}, M_{cit}, U_{cit})$, $\tilde{r}_{pit} = (L_{pit}, M_{pit}, U_{pit})$ and $\tilde{r}_{sit} = (L_{sit}, M_{sit}, U_{sit})$.

Step 3. The assumption which sets the equal importance of all management of organizational vulnerabilities' parameters can be introduced. With respect to this assumption, the normalized values of indicators i, i=1,,.,I in time period t, t=1,..,T can be represented by the volume of polyhedron which is denoted as $V_{it}, i = 1,..,I; t = 1,..T$.

$$V_{it} = \begin{vmatrix} M_{cit} & M_{pit} & 0 \\ M_{cit} & 0 & M_{sit} \\ 0 & M_{pit} & M_{sit} \end{vmatrix} = 2 \cdot M_{cit} \cdot M_{pit} \cdot M_{sit} \tag{1}$$

Step 4. The weighted normalized value of maintenance indicator i, $i = 1,..,I$ in time period t, t=1,..,T, is calculated:

$$d_{it} = w_i V_{it} \tag{2}$$

Step 5. Determine the rank of maintenance indicators according to $\min\limits_{i=1,..,I} d_{it}$.

Step 6. Determine the level of maintenance process vulnerabilities in time period t, $\tilde{MPV}_t$:

$$\tilde{MPV}_t = \frac{1}{I} \cdot \sum_{i=1}^{I} \tilde{d}_{it} \tag{3}$$

4. Illustrative example

Indicators that need to be assessed are: planning strategies (i=1), participation in exercises (i=2), capability and capacity of external resources (i=3), capability and capacity of internal resources (i=4) and organizational connectivity (i=5). The time period in which the maintenance process vulnerabilities in the SME are discussed is one year. This time period is a discretization, such that the discretization step is three months (quarter). The pair-wise comparison matrix of the relative importance of maintenance indicators is:

$$\begin{bmatrix} 1,1,1 & \tilde{R}_3 & \tilde{R}_3 & \tilde{R}_1 & \tilde{R}_4 \\ 1/\tilde{R}_3 & 1,1,1 & \tilde{R}_2 & \tilde{R}_1 & 1/\tilde{R}_2 \\ 1/\tilde{R}_3 & 1/\tilde{R}_2 & 1,1,1 & \tilde{R}_1 & \tilde{R}_1 \\ 1/\tilde{R}_1 & 1/\tilde{R}_1 & 1/\tilde{R}_1 & 1,1,1 & 1/\tilde{R}_1 \\ 1/\tilde{R}_4 & \tilde{R}_2 & 1/\tilde{R}_2 & \tilde{R}_1 & 1,1,1 \end{bmatrix} \tag{4}$$

The weights of the identified maintenance indicators are calculated by applying the proposed Algorithm (Step 1): $w_1 = 0.503$, $w_2 = 0.16$, $w_2 = 0.106$, $w_4 = 0.02$, $w_5 = 0.211$.

By using the proposed Algorithm (from Step 2 to Step 4) the weighted normalized values of maintenance indicators in each time period are given:

$d_{11} = 0.066$	$d_{21} = 0.0554$	$d_{31} = 0.0025$	$d_{41} = 0.0031$	$d_{51} = 0.0658$
$d_{12} = 0.0518$	$d_{22} = 0.1184$	$d_{32} = 0.0033$	$d_{42} = 0.0005$	$d_{52} = 0.0257$
$d_{13} = 0.0317$	$d_{23} = 0.0049$	$d_{33} = 0.0066$	$d_{43} = 0.0006$	$d_{53} = 0.046$
$d_{14} = 0.0211$	$d_{24} = 0.007$	$d_{34} = 0.0033$	$d_{44} = 0.0025$	$d_{54} = 0.0257$

Table 1: Fuzzy rating of parameter values in different time periods

Indicators of process vulnerabilities		Fuzzy rating of parameter values			
		t=1	t=2	t=3	t=4
i=1	Exposure	$\tilde{v}_3$	$\tilde{v}_2$	$\tilde{v}_2$	$\tilde{v}_4$
	Adaptive capacity	$\tilde{v}_5$	$\tilde{v}_4$	$\tilde{v}_3$	$\tilde{v}_4$
	Sensitivity	$\tilde{v}_2$	$\tilde{v}_3$	$\tilde{v}_3$	$\tilde{v}_2$
i=2	Exposure	$\tilde{v}_4$	$\tilde{v}_3$	$\tilde{v}_4$	$\tilde{v}_3$
	Adaptive capacity	$\tilde{v}_2$	$\tilde{v}_3$	$\tilde{v}_3$	$\tilde{v}_2$
	Sensitivity	$\tilde{v}_3$	$\tilde{v}_2$	$\tilde{v}_3$	$\tilde{v}_2$
i=3	Exposure	$\tilde{v}_5$	$\tilde{v}_4$	$\tilde{v}_3$	$\tilde{v}_4$
	Adaptive capacity	$\tilde{v}_4$	$\tilde{v}_3$	$\tilde{v}_4$	$\tilde{v}_3$
	Sensitivity	$\tilde{v}_4$	$\tilde{v}_3$	$\tilde{v}_3$	$\tilde{v}_3$
i=4	Exposure	$\tilde{v}_4$	$\tilde{v}_5$	$\tilde{v}_4$	$\tilde{v}_5$
	Adaptive capacity	$\tilde{v}_3$	$\tilde{v}_2$	$\tilde{v}_2$	$\tilde{v}_3$
	Sensitivity	$\tilde{v}_1$	$\tilde{v}_2$	$\tilde{v}_2$	$\tilde{v}_1$
i=5	Exposure	$\tilde{v}_3$	$\tilde{v}_2$	$\tilde{v}_2$	$\tilde{v}_2$
	Adaptive capacity	$\tilde{v}_4$	$\tilde{v}_3$	$\tilde{v}_2$	$\tilde{v}_3$
	Sensitivity	$\tilde{v}_1$	$\tilde{v}_2$	$\tilde{v}_1$	$\tilde{v}_2$

The rank of maintenance indicators in each considered time period is presented in Table 2.

Table 2: Rank of maintenance indicators in different time periods

Indicators	Rank of indicators in time period (t=1)	Rank of indicators in time period (t=2)	Rank of indicators in time period (t=3)	Rank of indicators in time period (t=4)
i=1	5	4	4	4
i=2	3	5	2	3
i=3	1	1	3	2
i=4	2	2	1	1
i=5	4	3	5	5

Based on the results presented in Table 2, it can be concluded that indicator (i=3) has the greatest impact on the maintenance process. It is necessary for the management team to take measures for improvement of this indicator in the first half of the year, such as implementing tools for improving workplace organization like 5S or visual management. In the third and fourth quarter, the indicator which has the smallest weighted normalized value is the indicator capability and capacity of internal resources (i=4). The measures needed to be taken regarding indicator improvement are defining an appropriate strategy, oriented to increasing the level of cooperation with external stakeholders (local government, banks and business partners).

The level of maintenance process vulnerabilities in each defined time period is calculated by applying the proposed Algorithm (Step 6), such that:

$\widetilde{MPV}_1 = 0.0386$, $\widetilde{MPV}_2 = 0.0399$, $\widetilde{MPV}_3 = 0.0179$ and $\widetilde{MPV}_4 = 0.0119$

The highest level of maintenance process vulnerability is in the second quarter (t=2) and the lowest maintenance process vulnerability is in the fourth quarter (t=4).

5. Conclusion

In the current business environment, organizations need to be engaged in a comprehensive and systematic process of prevention, preparedness, mitigation, response and recovery, and business continuity. In this paper, a new fuzzy model for vulnerabilities of the maintenance process is proposed. The management team define: (1) parameters of maintenance indicators and maintenance indicators, (2) the relative importance of the identified indicators, and (3) rating of parameter values. By applying a new fuzzy model, it can be determined: (1) the maintenance indicator which has the greatest impact on the maintenance process for each time period, and (2) the level of maintenance process for each time period. This paper proposes that a solution obtained in an exact manner is less burdened by the subjective views of decision makers and therefore is more accurate. The management team can quickly take appropriate management actions which enhance the performance indicators and reduce the negative impact on the maintenance process in the time period considered. With respect to values of the maintenance process, the management team controls the effects of the taken actions.

The following conclusion is made: (1) It is possible to describe the considered problem by formal language that enables the search for a solution by an exact method, (2) The uncertainties which exist in the model, can be described by fuzzy numbers, (3) All the changes, such as the changes in the number of maintenance indicators or their importance, can be easily incorporated into the model, and (4) The developed methodology is illustrated by a numerical example with real data.

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