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Optimization of the Maintenance Process Using Genetic Algorithms

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In this paper, we will present an approach for assessment and ranking of maintenance process performance indicators using the fuzzy set approach and genetic algorithms. Weight values of maintenance process indicators are defined using the experience of decision makers from analysed SMEs and calculated using the fuzzy set approach. In the second step, a model for ranking and optimization of maintenance process performance indicators and SMEs is presented. Based on this, each SME can identify their maintenance process weaknesses and gaps, and improve maintenance process performance. The presented model quantifies maintenance process performances, ranks the indicators and provides a basis for successful improvement of the quality of the maintenance process.

1. Introduction

Considering the fact that poor maintenance leads to loss of productivity, a reduction in profitability and therefore, in many cases, to a loss of clients and a general bad company image, maintenance function has become more and more important. An effective maintenance policy could influence the productivity and profitability of a manufacturing process through its direct impact on quality, efficiency and effectiveness of operation (Alsyouf, 2007).

In order to achieve maintenance objectives in accordance with business goals, it is necessary to measure maintenance performance. Well-defined performance indicators can potentially support the identification of performance gaps, between current and desired performance, and can provide an indication of progress towards closing the gaps (Muchiri et al., 2010). This is important for decision makers and managers to be able to find weak spots, and provide improvement actions. In order to enable decision-makers to choose the optimal maintenance performance indicators (in accordance with the desired results and focus on particular areas of the production system), it is necessary to assess and rank maintenance Key Performance Indicators (KPIs). Many authors have identified KPIs for maintenance performance measurement and have classified them based on specific aspects of performance measurement (Dwight, 1995; Tsang, 1999; Komonen, 2002; Wireman, 2005; Weber and Thomas, 2006). Parida and Kumar (2006) identified various issues and challenges associated with the development and implementation of a maintenance performance measurement (MPM) system. Alsyouf (2006) developed a framework for strategic MPM using a balanced scorecard approach. Parida and Chattopadhyay (2007) analysed and developed a multi-criteria hierarchical framework, for effective MPM, which is balanced, holistic and integrated to various levels of an organization, for regular use by stakeholders. Muchiri et al. (2010) carried out empirical analysis of MPM in Belgian industries. They determined the KPIs which are most commonly used, how they are chosen and how they can be effectively used in decision support and performance improvement. The authors went a step further and, in the next paper (Muchiri et al., 2011), performance indicators of the maintenance process and maintenance results were identified for each category and a conceptual framework was proposed. We used this framework as a basis for the assessment and optimized ranking of the defined maintenance process KPIs to find optimal solutions for improving the maintenance process.

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In this paper, the focus is on the development of a model for assessment of maintenance process quality using the fuzzy set and genetic algorithm approach. The presented approach was implemented and used in practice in 53 SMEs from the Serbian metal processing sector. Using fuzzy set theory and inputs from 197 managers from the analysed SMEs, weight values of maintenance KPIs were calculated. The maintenance process KPIs were ranked by multi-objective optimization genetic algorithm ranking. This is important for companies because it provides a platform to find weak spots, and provides improvement actions, comparing different maintenance processes and improves maintenance performance.

2. Definition of a maintenance process's metrics

Each process should be measured with one or two metrics that characterize the essentials of its performance. Such a metric is called a Key Performance Indicator or KPI (Weske, 2012). KPIs are very important for evaluation and assessment of the maintenance process, and companies overall. The definition of a KPI is not an easy task and could be assessed in many different ways. In this paper, we use maintenance process performance indicators (Table 1) which are defined in Muchiri et al. (2011). They outline the key elements that are important in the management of maintenance function.

Table 1: Maintenance Process KPI (Muchiri et al. 2011)

Category	KPI	Indicators	Description	Recommended Targets
Work Identification	KM1.1	Proactive work	Man-hours envisaged for proactive work/Total man hour's available (%)	75 % - 80 %
	KM1.2	Reactive work	Man-hours used for reactive work/Total man-hours available (%)	10 % - 15 %
	KM1.3	Improvement work	Man-hours used for improvement & modification/Total man-hours available (%)	5 % - 10 %
	KM1.4	Work request response rate	Work requests remaining in 'request' status for <5days/Total work requests (%)	80 % of requests
Work Planning	KM2.1	Planning Intensity/Rate	Planned work/Total work done (%)	95 %of all work orders
	KM2.2	Quality of planning	Percentage of work orders requiring rework due to planning/All work orders	< 3 % of all work orders
	KP2.3	Planning Responsiveness	Percentage of work orders in planning status for<5days/All work orders	> 80 % of all work orders
Work Scheduling	KM3.1	Scheduling Intensity	Scheduled man-hours/ Total available man-hours (%)	>80% of available man-hours
	KM3.2	Quality of scheduling	Percentage of work orders with delayed execution due to material or man-power	< 2 %
	KM3.3	Schedule realization rate	Work orders with scheduled date earlier or equal to late finish date/All work orders (%)	> 95 % of all work orders
Work Execution	KM4.1	Schedule Compliance	Percentage of work orders completed in scheduled period before late finish date	> 90 %
	KM4.2	Mean Time To Repair	Total Downtime/No. of failures (Hours)	
	KM4.3	Manpower Utilization rate	Total Hours spent on tasks/Available Hours (%)	> 80 %
	KM4.4	Manpower Efficiency	Time Allocated to Tasks/Time spent on tasks (%)	
	KM4.5	Work order turnover	No. of completed tasks/ No. of received tasks (%)	
	KM4.6	Backlog size	No. of overdue tasks/ No. of received tasks (%)	
	KM4.7	Quality of Execution	Percentage of maintenance work requiring rework	< 3 %

The weight values of indicators were defined using the experience of decision makers from 53 metal processing SMEs (total number of 197 persons). Their statements were described by linguistic expressions which are modelled by triangular fuzzy numbers: Work Identification – 0.24 (Proactive work – 0.15; Reactive work – 0.3; Improvement work – 0.25; Work request response rate – 0.3); Work Planning – 0.16 (Planning Intensity/Rate – 0.5; Quality of planning – 0.2 Planning Responsiveness – 0.3); Work Scheduling – 0.29 (Scheduling Intensity – 0.3; Quality of scheduling – 0.3; Schedule realization rate – 0.4); and Work Execution – 0.31 (Schedule Compliance – 0.1; Mean Time To Repair – 0.3; Manpower Utilization rate – 0.05; Manpower Efficiency – 0.1; Work order turnover – 0.15; Backlog size – 0.2; Quality of Execution – 0.1). These weight values are not fixed and every SME can change them according to their experiences and needs.

3. Genetic algorithms for ranking of criteria and evaluation of maintenance process quality in SMEs

The MATLAB GA toolbox is used in order to rank KPIs as well as to rank SMEs. MATLAB is used as an easy to learn and reliable environment and the following parameters were set:

- Population type was double vector,
- Selection function was stochastic uniform already existing in MATLAB,
- Mutation function was constraint dependent,
- Crossover function used in this model was scattered, and
- Stopping criteria for this function was 100 generations set by default.

The method used in this paper is a Pareto optimization method, which belongs to the category – "Search prior to the Decision" group of methods. The Pareto GA implemented in this paper works with two objective functions. The presented GA can easily be modified to work with multiple functions.

The criteria used for the ranking of maintenance sub process indicators were the maximization of the sum and the variance of weight amounts. In this paper, the sum and the variance of weight amounts of maintenance sub process indicators in 53 SMEs were analysed. Four maintenance process indicators and 17 maintenance sub process indicators were considered to determine the individual rank of each SME.

The main goal of ranking is the weight value determination w_i, which leads to the definition of the variance minimum of all weights for maintenance process and sub process indicators and the sum of maximum weight for all maintenance process and sub process indicators.

The ranking was performed using MATLAB tools for multi-objective optimization by GA. Both objective functions are defined separately. So, the formal definition of the optimization problem is:

maximum $S_{total} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{l} a_{ijk} * Kp_j * Kp_{jk}$, and

minimum $Var = \sqrt{\frac{\sum_{i}^{m} \sum_{j}^{n} \sum_{k=1}^{l} \left(a_{ijk} * Kp_j * Kp_{jk} - \bar{a}\right)^2}{m * k}}$, with the condition $\sum_{i=1}^{n} w_i = 1$, $0 \le w_i \le 1$, where ***m*** is the number of SMEs, and ***k*** is the number of maintenance sub process indicators.

The ranking of indicators of a process and sub process of maintenance was done using a similar procedure. The only difference is the weight parameters definition ***w***

$$w_j = \frac{\sum_{k=1}^{m} \sum_{k=1}^{l} a_{ijk} * Kp_j * Kp_{jk}}{S_{total}} \tag{1}$$

where w_j is the participation of the *j* type of maintenance process indicators in the total sum and

$$w_{jk} = \frac{\sum_{k=1}^{m} \sum_{j=1}^{n} a_{ijk} * Kp_j * Kp_{jk}}{S_{total}} \tag{2}$$

where w_{jk} is the participation of the *jk* type of maintenance sub process indicator in the total sum.

The general task is to develop a software solution for the ranking of SMEs based on evaluation of their sub processes, metrics and indicators, and ranking of sub process indicators. The software solution is flexible in the sense that enables changes in the number of indicators as well as changes in the values of weights for each criteria. In addition, the software solution should enable the comparison and ranking of the

maintenance process in different companies. This will lead to the definition of potential managerial actions that could be taken in order to improve the quality of the maintenance process.
The first step was the development of a solution based on MATLAB that is presented in Figure 1. For each maintenance sub process, its indicators and weights are presented (from KM1 to KM4), as well as the indicators and weights for each sub process (from KM1.1 to KM4.7). After the data input, the rank of each maintenance sub process for all analyzed SMEs is calculated. The obtained results below are presented in the following text and in Figure 3.
The main idea was to compare and contrast assessment of the maintenance process in different fields, which will enable the quality of the maintenance process to be benchmarked.

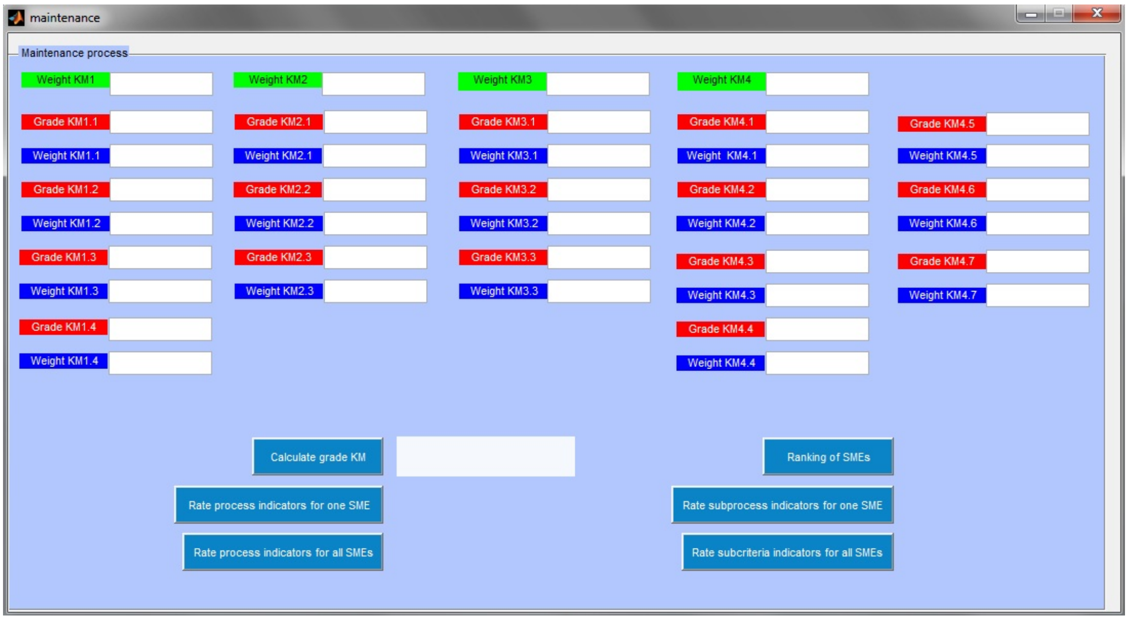

Figure 1: The application screen shot in MATLAB

To rank the maintenance process indicators, two functions are used: the weighted score of the maximum sum of the observed indicators and the weighted score variance of the observed indicators. After performing calculations, both functions are at a point on the Pareto front (Figure 2). Pareto optimal solutions are shown in asterisks. Each of these asterisks is one possible solution, from the set of optimal solutions, ranking the maintenance process indicators in the analyzed SMEs. The indicators' final ranking for the analyzed SMEs, as a mean value of all ranks obtained in points of the Pareto front, is calculated.
The ranking of the maintenance sub processes (Figure 2) showed that the *Quality of scheduling* sub process indicator (KM3.2) has the most important rank in the scope of the maintenance process. This indicates that delaying the execution of work orders due to material or man-power has the greatest impact on the efficiency and effectiveness of the maintenance process, and therefore on its quality. The *Work request response rate* sub process indicator (KM1.4) has the second most important rank because it is very important for the efficiency of the maintenance process that work requests remain in 'request' status for less than 5 days. The *Mean Time to Repair* sub process indicator (KM4.2) is the third indicator for which the importance of – total downtime compared to number of failures in hours stands out. The total downtime compared to number of failures must be as short as possible because of its effect on the SMEs' productivity. It is also important for efficiency of maintenance process to properly schedule man-hours (*Scheduling Intensity* – KM3.1).

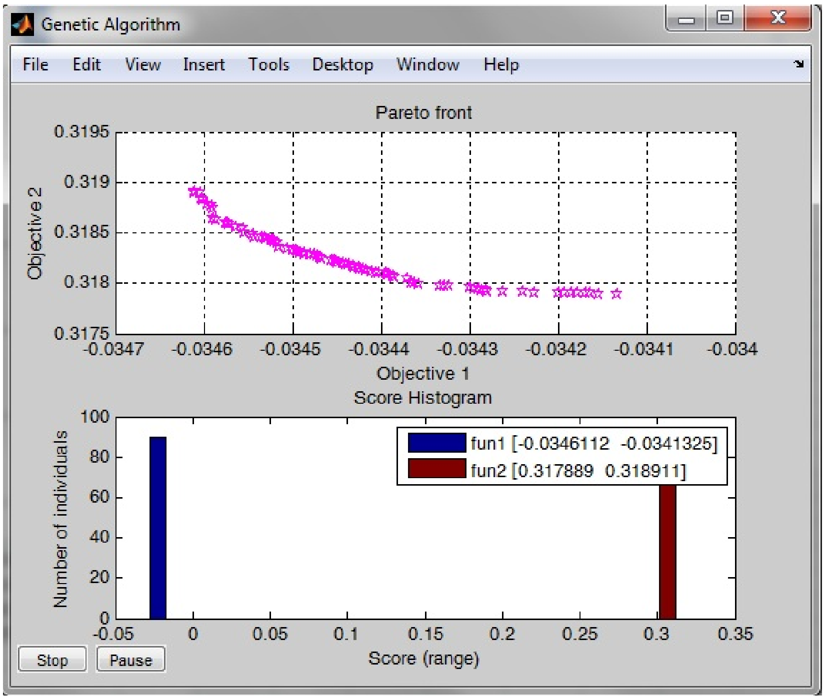

Figure 2: Pareto optimal solutions for ranking the maintenance process indicators

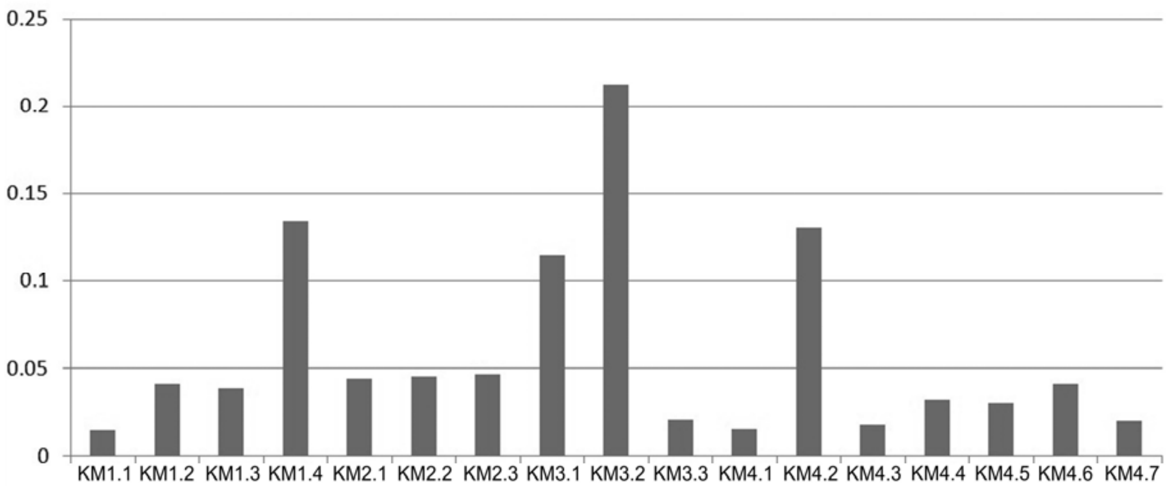

Figure 3: Rank of the maintenance sub process indicators

All indicators of the *Work Planning* sub process (KM2.1, KM2.2 and KM2.3) for the analyzed SMEs are relatively significant, while the *Proactive work* sub process indicator (KM1.1) and *Schedule Compliance* sub process indicator (KM4.1) have the lowest importance, the reason being that Serbian SMEs have often neglected proactive maintenance, and work orders completed in a scheduled period before a late finish date, are rare. The rest of the sub process indicators have approximately the same importance for the analyzed SMEs.

These ranks clearly show which KPIs were at a satisfactory level and which were not, so the necessary actions could be taken. SMEs can improve the quality of their maintenance process performance with appropriate actions, based on the rank of their maintenance process indicators. Since each SME could calculate its own rank according to the values of its indicators, the next important issue will be to find a way for optimization of the selected KPIs. The goal could be to assess its own KPIs, identifying its strengths and weaknesses by comparison to the leading and average one. In addition, each SME could develop its own scenario for improvement of learning from the leading organizations.

4. Conclusion

Measurement and ranking of indicators of the maintenance process, and their improvement, is an important task in any company because it allows assessment of the quality of the maintenance process. In this paper, a novel approach to the ranking and assessment of maintenance process performance KPIs, as well as overall ranking of SMEs according to their maintenance process KPIs, is presented.

The approach is based on evaluations of KPI weights by experts (the fuzzy rating of each decision maker was described by using five linguistic expressions which are modelled by triangular fuzzy numbers). These weights were the input for ranking and optimization using MATLAB GA toolbox. The approach was tested on 53 SMEs from the Serbian metal processing sector. Their inputs (values for KPIs) were used for the calculation and ranking of maintenance process KPIs.

The presented solution has its practical implementation because it could provide: identification of strengths and weaknesses (comparing KPIs), learning from a leading organization (in prioritization of KPI improvement) and improvement of maintenance process performance. Moreover, the presented solution could be a starting point for further improvement because the optimization of specific KPIs could be accompanied by suggested strategies and/or tools.

The limitations of the specific research are related to the selection of SMEs (SMEs from the Serbian metal processing industry). Further research will include maintenance cost KPIs and maintenance equipment KPIs in order to see the relationship between these KPIs in Serbian metal processing SMEs and identify the most influential KPIs and, based on this, find a space for improvement of the maintenance process. Also, further research should be directed to increasing the number of SMEs, industries, countries etc. In addition, this approach could be used as the basis for more complex solutions and decision support systems.

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