Lecture Notes in Mechanical Engineering

Volodymyr Tonkonogyi ·
Vitalii Ivanov · Justyna Trojanowska ·
Gennadii Oborskyi · Anatolii Grabchenko ·
Ivan Pavlenko · Milan Edl · Ivan Kuric ·
Predrag Dasic *Editors*

Advanced Manufacturing Processes II

Selected Papers from the 2nd Grabchenko's International Conference on Advanced Manufacturing Processes (InterPartner-2020), September 8–11, 2020, Odessa, Ukraine

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Preface

This volume of Lecture Notes in Mechanical Engineering contains selected papers presented at the 2nd Grabchenko's International Conference on Advanced Manufacturing Processes (InterPartner-2020), held in Odessa, Ukraine, during September 8–11, 2020. The conference was organized by Odessa National Polytechnic University, National Technical University "Kharkiv Polytechnic Institute", Sumy State University, and International Association for Technological Development and Innovations.

InterPartner-2020 focuses on promoting research and developmental activities, intensifying scientific information interchange between researchers, developers, and engineers.

InterPartner-2020 received 133 contributions from 13 countries around the world. After a thorough peer-review process, the program committee accepted 82 papers written by authors from 13 countries. Thank you very much to the authors for their contribution. These papers are published in the present book, achieving an acceptance rate of about 62%.

We want to take this opportunity to thank members of the program committee and invited external reviewers for their efforts and expertise in contribution to reviewing, without which it would be impossible to maintain the high standards of peer-reviewed papers.

Thank you very much to keynote speakers: Vitalii Ivanov (Ukraine), Dagmar Caganova (Slovak Republic), Justyna Trojanowska (Poland), Jan Pitel (Slovak Republic), Slawomir Luscinski (Poland) and Milan Edl (Czech Republic) for sharing their knowledge and experience.

The book "Advanced Manufacturing Processes II" was organized into seven parts according to the main conference topics: Part 1—Production Planning, Part 2—Design Engineering, Part 3—Advanced Materials, Part 4—Manufacturing Technology, Part 5—Machining Processes, Part 6—Process Engineering, and Part 7—Quality Assurance.

The first part "Production Planning" includes studies in the intelligent predictive decision support system, the use of augmented reality solutions in enterprises, ways for production line balancing and improvement of assembling technologies at production lines, and application of lean analysis in complex product manufacturing process. This part also includes studies in the field of the improvement of manufacturing processes, printing industry, logistical issues, as well as ecological activities in the use and recycling of products.

The second part "Design Engineering" includes studies in mathematical modeling and numerical simulation of the operating processes, including mixing, delamination, and oscillations. Notably, elastic characteristics, deflected modes, dynamic state, and structures' failure are analyzed in this part. This part also consists of kinematics and dynamics of a particle, modeling of hydraulic systems, and design optimization of structures. The possibilities of using engineering methodology for modeling the system "spindle assembly–cutting system" during machining are additionally included in this part.

The third part "Advanced Materials" presents studies in the field of thermo-mechanical properties of composites, deformation of alloys, mass balance in the deposition of ionic-plasma coatings, and ultrasonic treatment of polymers. This part also includes studies aimed at improving properties for structurally inhomogeneous materials, carbide coatings, and polyurethane foam molding. Problems related to the quality assessment, quantitative metallography, and radial isostatic compression of porous materials are also solved in this part.

The fourth part "Manufacturing Technology" is based on the manufacture of parts, their treatment, and technological support, as well as on numerical simulation of the technological processes. The environmental impact of additive manufacturing, minimization of roughness, and errors are also included in this part. Notably, improvement of characteristics for cutting tools, the use of solid lubricants, the influence of technological factors on the reliability, wear resistance, stability, and quality parameters are analyzed in this part.

The fifth part "Machining Processes" aims to develop and implement methods for multi-criteria optimization of machining and finishing processes and improvement of the quality for cutting tools, modeling of tool surface treatment, and simulation of shaping processes. Additionally, issues related to the development of dynamic models for the machining processes using wear-resistant and self-adaptive coatings are analyzed in this part. Ways for simulation of vibrational turning, tapered thread machining, fine boring, and double-sided grinding are also developed in this part.

The sixth part "Process Engineering" includes studies in the fields of parameter identification of heat supply systems and refrigeration capacity of air-conditioning systems, as well as the optimal design of combustion engines and the improvement of characteristics for atomizers. Substantiation of pressure compensator construction for nuclear power plants is also included in this part. Notably, the part analyzes petroleum and bio-components in fuel compositions, dynamic processes of mechatronic systems, the temperature in elements of wind power installations, thermal loading and air cooling of engines, as well as cavitation and output characteristics of hydraulic devices.

The seventh part "Quality Assurance" includes issues related to ensuring the quality of training engineers using a virtual environment, information quality in energy management systems, and auditing sustainable development for organizations. This part presents ways to improve measuring tools and test methods for nanomaterials, chemical parameters of mineral waters, and the selection of lithological layers. Additionally, ensuring the software assistance for the smart factory production line and industrial robots certification are also analyzed.

We appreciate the partnership with Springer, StrikePlagiarism, and EasyChair for their support during the preparation of InterPartner-2020.

Thank you very much to InterPartner Team. Their involvement and hard work were crucial to the success of the conference.

InterPartner's motto is "Science unites people together".

September 2020

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Vitalii Ivanov
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Contents

Production Planning

Intelligent Predictive Decision Support System for the Maintenance Service Provider

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Abstract. A maintenance process of internal vehicle transport is important from the production companies and also service providers. Failures of transport vehicles for a production company mean difficulties in the realization of production and auxiliary processes. Failures of transport vehicles for a service organization means those employees of the organization are assigned to carry out service activities for a longer time. This issue can be a particular problem, especially for small service organizations. Hence, in order to plan the maintenance activities, it is appropriate to predict failures to prevent them by undertaking adequate preventive actions. In this work, the failure risk was calculated based on the data from the maintenance processes collected. Additionally, it is proposed the solution, especially for small maintenance service providers, which can be used for maintenance activities taken under consideration the criticality of internal vehicles. The method presented in the article, which supports decision making regarding service planning, can help companies providing maintenance outsourcing services.

Keywords: Intelligent decision making tool · Fuzzy logic · Outsourcing of maintenance processes

1 Introduction

Companies specializing in technical infrastructure service (machinery and equipment, installations, means of transport) currently operate in almost all possible areas of the market, providing services for both commercial and manufacturing enterprises. Along with the ubiquitous automation and computerization, the demand for services related to, among others, repair, maintenance, and periodic inspection of machines and devices is growing. These needs create a huge field of activity for maintenance companies. Concerning manufacturing enterprises, maintenance service providers support: (i) non-functional areas, such are office heating, air conditioning, lighting; (ii) auxiliary areas to production, such as water treatment for production facilities, air compression, transport vehicles and storage facilities; (iii) production area such as production equipment.

The maintenance tasks realized by service providers are extremely important because the continuity of operation of the processes carried out by the clients of the maintenance company and their success depends on efficiently functioning machines,

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devices, and means of transport. Also, regular maintenance of devices extends their life cycle and increases the efficiency of their operation and also has a positive effect on production efficiency [1, 2].

Due to the wide spectrum of maintenance services, running a maintenance company is a difficult task. The main problems of managers of such a company include the need to coordinate the dates of planned maintenance activities (e.g., inspections) and unplanned activities related to fixing the failures at customers' facilities located in different places. On the other hand, service technicians often struggle with maintaining machines from different manufacturers, which forces them to comply with various control procedures and service principles.

Enterprises implementing outsourcing maintenance contracts tend to achieve the "perfect balance" between costs and the availability and technical condition of equipment covered by the service contract. It is mainly done through: adaptation of exploitation strategies to machines depending on their criticality, adjustment of the frequency of preventive works on machines to their criticality, and technical condition.

Machine criticality is a key element for both the company and the maintenance service provider. The same machine can be critical in one enterprise, but not in another. An enterprise providing maintenance services should categorize machines together with client employees to include crucial and specific factors. The results of the categorization will be the basis for determining the scope of maintenance activities that should be taken to keep the risk of failure at the level required by the customer.

Each failure resulting in a stoppage of the machine, production line or even the entire plant may have several consequences, such as costs of removing the failure (e.g., cost of spare parts, cost of work of employees), reduction of product quality or difficulties in the entire supply chain. In addition to purely financial consequences, the occurrence of failure may cause safety risks for machine operators and third parties in the vicinity of the machine; also, it may harm the natural environment [3, 4]. Conducting a criticality analysis enables the selection of an appropriate maintenance strategy [5]. It should be emphasized, however, that selecting the strategy is a complex technical, economic and organizational task, requiring knowledge of market needs (as a recipient of maintenance services), the balance of total costs as well as profits, and the technical capabilities of the used equipment. When selecting the strategy, the specificity of tasks performed by a given company and key problems, that are generated in connection with maintenance processes, are of great importance.

Another element after determining the maintenance strategy, important for the implementation of the service company's activities, is the adjustment of the frequency of preventive work on machines to their criticality and technical condition. Planning and scheduling of maintenance are perceived as the "center" of maintenance management [6]. What and when it is to be performed directly affects production (availability of machinery and equipment), safety (tasks planned are generally safer than unplanned), environment (compliance with legal and sustainable requirements), costs (additional working hours) and indirectly marketing (availability of products for the client) [7]. At the same time, planning and scheduling of maintenance are influenced by the availability of financial resources, human resources (e.g., availability of competences) [8], information (e.g., historical data on operational events) and material and technical resources (internal availability and the possibility of acquiring them from a market environment).

Planning is a decision-making process that deals with the allocation of resources to jobs, in given time intervals, and its task is to optimize one or more goals [9]. Resources and tasks in any organization can take different forms. They can be machines in a repair workshop or people carrying out tasks. The decision to implement many tasks exploiting shared resources (and this situation occurs in enterprises providing services) is very complicated.

Different types of machines are assigned to different periods of service, depending on the frequency of failures and their criticality. One of the challenges is to determine the right time interval between services and their ranges. It is necessary to ensure that:

- costly and unnecessary maintenance activities were not performed long before the actual occurrence of the failure;
- costly activities caused by the failure as a consequence of too long time intervals between planned preventive actions were not necessary.

The need to plan maintenance and repair activities, the variety of planning methods used, and the resulting benefits are the subject of many publications [10–14].

2 Literature Review

The review presents some solutions supporting maintenance transport. In research [15], the case study takes its starting point in the perspective of an actor considering how to develop vehicle maintenance services for its customers and points at the need to enable understanding of the conditions for vehicle maintenance, which necessitates identification and analysis of the variety across transport service settings. The main objective of the work [16] is to design a system for diagnosis, measurement, and improvement of productivity aimed at quality of service. The result in the study [17] is researched on how to achieve an effective fleet maintenance planning in transport companies, which contributes to increasing the fleet energy efficiency and in achieving the companies' goal. Some decision systems are also presented in the works [18–20].

Although the literature on the subject presents some solutions to decision support systems, in the field of vehicle transport maintenance, there is still a lack of dedicated, simple, low-cost, and intelligent solutions, especially for small service providers. That is why the main research problem in this paper is: How to support maintenance service providers in planning their maintenances tasks based on the criticality of vehicles and predict adequate maintenance activities, especially in a small service provider?

This paper is organized as follows. First, a short literature review related to maintenance service providers is presented. Moreover, the research problem is posed. Next, the analysis of maintenance activities frequency based on case study service provider is introduced. In the third chapter, the intelligent predictive decision support system for the services provider is presented. Finally, the main conclusion and added value of this work are discussed.

3 Research Methodology

3.1 Structure of Internal Vehicle Transport Classification

The paper presents a practical analysis of the process of maintaining internal transport, the main purpose of which is to keep vehicles in readiness for work. The analysis was carried out based on the principles of organization and implementation of machine maintenance activities for various vehicles and used in various locations. The planning of maintenance activities of the service provider must anticipate failures to take them and take appropriate preventive action. In this analysis, the data is based on data collected in maintenance processes performed by the service provider.

The subject of the following analyses is Internal Vehicle Transport (*IVT*). Different criteria were used to classify IVT, such: type of IVT (internal combustion vehicle, electric), a model (m_1, m_2,…,m_n), age, and working time (WT) (Table 1). Ranges for criteria were identified during the data analysis from the case company and concerning requirements from internal vehicle producers. For analysis, the data delivered by the service provider were used. The boxplot in Fig. 1 shows the value distribution of Age (A) and working time (WT). Only the boxplot of working time shows the outliers, which do not influence further analyses.

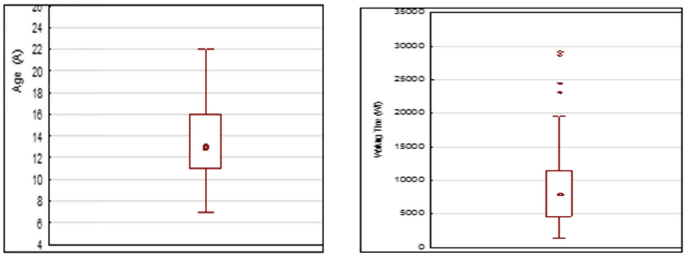

Fig. 1. The boxplot of value distribution of Age (A) and Working Time (WT).

3.2 Maintenance Activities Analyses

The first of the study was to identify the type and the frequency of maintenance activities (*MA*). Mainly the type of maintenance activities was divided into two types planned and unplanned activities. To identify the frequency of maintenance activities to criteria were analyzed: age (A) and Working Time (WT). The analysis showed that the age of IVT is in the range of 7–22 years, and the maximum value of the working time of IVT is almost 30000 h. Three categories of analyzed criteria have been established: *High (H), Medium (M))* and *Low (L)* (Table 1). The criteria categories have been established based on authors and service organization experience.

Table 1. Classification criteria of IVT.

Categories	Criteria	Age of IVT (A) [years]	Working time (WT) of IVT [hours]
	L - Low	<8	<8000
	M - Medium	8–16	8000–16000
	H - High	>16	>16000

To analyze the frequency of maintenance activities of each IVT category, the maintenance activities frequency *(MAF)* indicator, according to Eq. (1), was calculated.

$$MAF = \frac{NoMA_C}{\sum NoMA} \tag{1}$$

where: *MAF* – the maintenance activities frequency, *NoMAc* – many maintenance activities in every category (considering *A* and *WT*),

$\sum NoMAF$– the total number of maintenance activities in the analyzed time.

Table 2 shows the obtained results, the value of *the MAF* indicator in each category.

Table 2. The value of the *MAF* indicator in each category.

Age (A) of IVT [years]		L	M	H
Working time (WT) [hours]	L	0.08	0.28	0.16
	M	0.05	0.22	0.08
	H	0.02	0.11	0.00

The experience of authors and personnel of service organizations let to identify the risk level of the *MAF* indicator. The level of risk of *the MAF* indicator was divided into three categories: Low, when the value of *MAF* is less than 0.10, Medium when the value of *MAF* is in the range 0.10 to 0.20, High when the value of the *MAF* indicator is more than 0.20 (Table 3). According to these assumptions, the risk level of *MAF* for every category was specified and presented in Table 4.

The possible use of the presented matrix of risk has been proved with workers in the analyzed service organization. In order to provide any circumstances (especially if the values of criteria are near to the border of the ranges), it is important to use an approach based on fuzzy logic to support the *MAF* indicator.

Table 3. The *MAF* categories.

The categories	Low	Medium	High
The value	<0.10	0.10–0.20	>0.20

Table 4. The risk level of *MAF*.

Criteria	Age (A) [years]			
		Low	Medium	Hight
Working time (WT) [hours]	Low	Low	High	Medium
	Medium	Low	High	Low
	High	Low	Medium	Low

4 Results

4.1 Process of Fuzzy Interference

The shown case study described in the paper, a Mamdani-type process of fuzzy inference is utilized. The membership functions were formulated, taking into account the values of the A and WT. However, it might be changed membership functions according to maintenance experts. Figure 2 presents the total view of the suggested fuzzy system of risk importance assessment. To calculate the risk rank, there is the option to choose A and WT, as the inputs to the fuzzy system. Because the Mamdani type fuzzy inference process is easy to understand and the most intuitive, so it was used to present that analyzed case study.

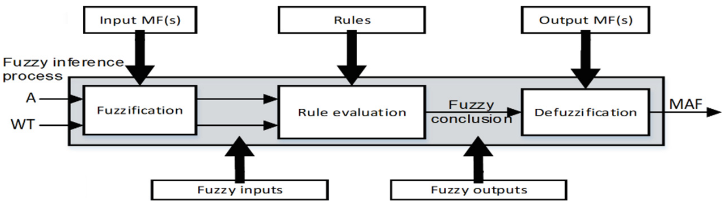

Fig. 2. Fuzzy Interference Process.

In the proposed Mamdani Fuzzy Interference System, two quantitative inputs were used *(A)* and *(WT)*, and output is the *MAF* indicator. The MATLAB (R2019b) was used to implement the proposed fuzzy inference process [21] (Fig. 3).

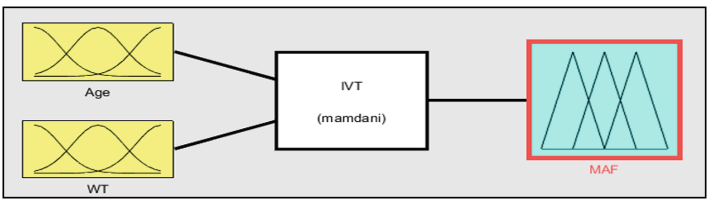

Fig. 3. Designer of Fuzzy Logic (Matlab R2019b).

4.2 Parameters of Fuzzy Interference System

For the inputs (*A*, *WT*) and output (*MAF*), the membership functions *MFs* were specified. In this paper, the functions of Gaussian membership available in MATLAB (R2019b) were incorporated by the authors for input *A* and *WT*, were used [21, 22] The curve of Gaussian membership function is described by the Eq. (2):

$$f(x) = exp^{\frac{-0.5(x-c)^2}{\sigma^2}} \quad (2)$$

where σ is the standard deviation, and *c* is the mean. Figure 4 presents the Gaussian membership function (GMF) for inputs *A* and *WT*.

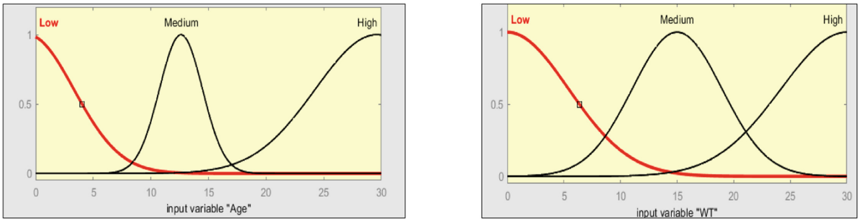

Fig. 4. GMF of *A* and *WT*.

Based on the work [23], the authors' and service organization experience, and in order to reduce the difference regarding the mathematical modeling and the practical implementation, the triangular membership functions for output *MAF* were used (3).

$$y = \text{trimf}\,(x, [x\ b\ c]) \quad (3)$$

The curve of the triangular membership function is a vector x, and it depends on three parameters a, b, and c. The b parameter is the triangle peak, and the a and c parameters determine the "feet". The membership functions for output *MAF* was determined based on the ranges presented in Table 3 (see Fig. 5). Based on Table 4, the fuzzy rule base was established (see Fig. 6).

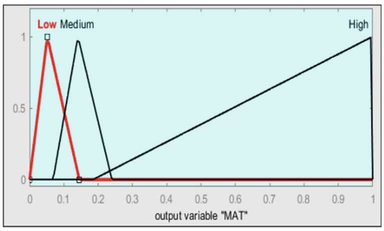

Fig. 5. A rule base for proposed FIS.

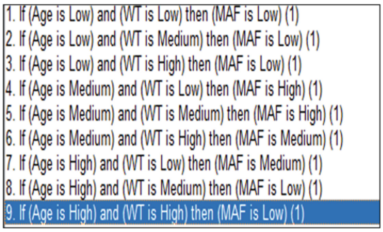
1. If (Age is Low) and (WT is Low) then (MAF is Low) (1)
2. If (Age is Low) and (WT is Medium) then (MAF is Low) (1)
3. If (Age is Low) and (WT is High) then (MAF is Low) (1)
4. If (Age is Medium) and (WT is Low) then (MAF is High) (1)
5. If (Age is Medium) and (WT is Medium) then (MAF is High) (1)
6. If (Age is Medium) and (WT is High) then (MAF is Medium) (1)
7. If (Age is High) and (WT is Low) then (MAF is Medium) (1)
8. If (Age is High) and (WT is Medium) then (MAF is Low) (1)
9. If (Age is High) and (WT is High) then (MAF is Low) (1)

Fig. 6. A rule base for proposed FIS.