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An Approach to Supporting the Selection of Maintenance Experts in the Context of Industry 4.0

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Abstract: (1) Background: In recent years, many studies regarding the issues of improving the management and effectiveness of the maintenance department of manufacturing companies, in the context Industry 4.0, have been published. This makes it necessary to establish a research gap in the approach to obtaining support in realising management tasks in the maintenance area in the selection of appropriate employees to perform the given activities. (2) Methods: This article uses literature studies and empirical research results from manufacturing companies, in order to determine the approach in supporting the selection of maintenance experts. In the approach, the method used—which is based on rules should there be future any formalisation of the data—is also the Fuzzy Analytic Hierarchy Process (FAHP), which analyses the importance of a given competence, within a manufacturing resource, to undertake repairs. (3) Results: The innovative approach towards the selection of expert workers in a maintenance department is created, in part, in the form of an implemented web-application. The novelty of the "maintenance expert selection map", so-called, is the provision of formal procedures for describing the competence of each maintenance worker and defining the best "state of nature". (4) Conclusions: In the research that is presented here, the practicality for maintenance managers in the "maintenance expert selection map" was established. This map describes the competence of workers for selecting them for repair work within a given manufacturing resource; the scope of employee training was also determined in this research.

Keywords: maintenance expert; competence; decision support

1. Introduction

The implementation of the Industry 4.0 concept within manufacturing enterprises was, and still is, the objective of many research papers [1–4]. Maintenance in manufacturing companies plays a crucial role in improving their competitiveness [5]. Moreover, companies should develop and implement those models that have already been employed and that can predict reliable production in operation, according to the Industry 4.0 paradigm [6].

Human operators are key resources within a smart manufacturing company [7], since such workers are aware of specific technological processes; however, one can still observe the need to obtain support in the selection of appropriate employees, in order for them to undertake given activities. Maintenance department managers expect that, in the event of a breakdown, they will receive a list of those employees whose competence will guarantee that the machine will be repaired in the shortest time in real time.

The approach to the selection of expert workers needs to be computerised and codified, while using data of a specified format, in order that it may prove to be useful. According to [8], the formal representation of the competence of workers is the key factor of the model's effectiveness. Moreover, they stated that there exists a lack of the representation of competence for "Diagnosis" as well as

"Management" tasks that were carried out in maintenance departments based on the literature review of 74 research papers; it is clear that these competences are primarily associated with employees performing these processes in the company.

Our proposed approach focusses on supporting management tasks that were carried out in the maintenance department and it includes the following elements: (1) Defining the type of failure for each manufacturing resource, (2) Defining the parameters of each type of failure for each maintenance worker, (3) Defining the competences of each maintenance worker, (4) Defining the importance of competence while using the Fuzzy Analytic Hierarchy Process (FAHP) method, (5) Defining the "state of nature" for each manufacturing resource regarding the employee, and (6) Selecting the maintenance expert for the repair of the manufacturing resource. Our approach is also partly investigated in the form of a web-application and is presented, based on a case study. The problem in this paper is how to assess the competences of maintenance workers in manufacturing companies and how to select the employees with the appropriate competences to undertake the repair of a given machine in companies.

2. Supporting the Selection of Expert Maintenance Workers in the Context of Industry 4.0

In the literature, many examples of the system supporting work in the maintenance department within the context of Industry 4.0 are to be found.

Ni et al. [9] studied the extra hidden opportunities for preventive maintenance (PM) during production time without violating the requirements of system throughput. The authors created a mathematical prediction model to identify PM opportunity windows for large production systems based on real-time factory information system data. Ni and Jin [10] presented new decision support tools that are based on mathematical algorithms and simulation tools for effective maintenance operations. The system enables the short-term identification of throughput bottlenecks, estimates the windows of opportunity for maintenance, prioritises maintenance tasks, jointly produces and maintains scheduling systems, and maintains staff management. The system was implemented in an automotive manufacturing area. Xiao et al. [11] developed an optimisation model in order to minimise the total costs, namely, production costs, preventive maintenance costs, minimal repair costs for unexpected failures, and delay costs. They used genetic algorithms to illustrate the proposed model. Jin et al. [12] proposed an analytical, option-based cost model for scheduling joint production and preventive maintenance when demand is uncertain. They obtained the optimum number of preventive maintenance work-orders within a production system using the model.

Many articles deal with the application of augmented reality (AR) or virtual reality, to support maintenance activities. Massoni et al. [13] present an application for remote maintenance, which is based on off-the-shelf mobile and augmented reality (AR) technologies [14]. The application enables a skilled operator, in a control room, to be remotely connected to an unskilled operator, located where maintenance has to be performed. Technological limitations problems and the incorrect use of AR technology in the maintenance area were analysed. Securati et al. [15] created and adopted a controlled and exhaustive vocabulary of graphical symbols, to be used in augmented reality, to represent maintenance instructions. They identified the most frequent maintenance actions that were used in manuals and converted them into graphical symbols. Roy et al. [16] analysed the foundations and technologies that are required to offer the maintenance service for years to come.

In the literature, the adoption of the Condition-based Maintenance (CBM) approach, within the context of Industry 4.0, is to be found. CBM can be treated as the decision making strategy that is based on observation of the system within a manufacturing company and/or its components [17], as part of the main "Detect-Predict-Decide-Act" paradigms. The subject of current research is the "Decide" phase [18]. In the CBM approach, decisions are taken based on information that is collected by monitoring the condition [19] using various kinds of techniques, such as AI technologies, comprising ANN, the rule-based, expert system, and the Bayesian Network [20].

Therefore, the approach to Supporting the Selection of Maintenance Experts, which contributes the method used—which is based on rules should there be any future formalisation of the data—is also the Fuzzy Analytic Hierarchy Process (FAHP). This approach analyses the importance of a given its competence to undertake repair work within a manufacturing resource and it is defined and developed for the phase: "Decide" in the CBM approach.

Moreover, Belkadi et al. [21] performed a comparative analysis of decision support systems that are dedicated to maintenance departments, such as the 'Knowledge' based system for industrial maintenance [22] and the 'Intelligent' system for predicting breakdowns and monitoring industrial machines [23], which have the advantage of providing their solutions in the form of functionality, or, to put it another way, the transformation and adaptation of expert knowledge.

The management of competence in Industry 4.0 aims to identify not only the competences required within a company, but also the critical gaps in competences within a company. According to [24] and our previous research [25] and, as based on the survey and data obtained from 85 German and Polish Manufacturing Enterprises, the core competences, which are needed in manufacturing companies, in terms of Industry 4.0, were defined as technical, methodological, social, and personal.

Our proposed approach allows for managers to select maintenance department expert workers; the main functionalities of these innovations are:

- Integrating, with the data already collected, details from the information system implemented, of the time spent by each worker in repairing each type of failure in each manufacturing resource.
- Providing formal procedures for describing the competence of each maintenance worker.
- Defining the best natural state—meaning indicating those workers, the selection of whom will guarantee the maximum availability of the manufacturing resource.
- Assisting in the selection of maintenance expert.

3. An Approach to Selecting a Maintenance Expert

The proposed approach to presenting the selection of maintenance experts—based on their competences—for repairs within a manufacturing resource provides an opportunity to denote a particular worker as the expert worker within the maintenance department.

The approach to selecting a maintenance expert (Figure 1) is in line with the concept of reliability-centered maintenance (RCM). RCM can be treated as the reactive, preventive, and proactive maintenance practices that are introduced within a company [26]. It is also the approach to capturing the reason of downtime using two stages: (1) determine the critical components of the system and (2) application of decision rules to define categories of predictive maintenance (PM) [27]. The construction of the proposed approach corresponds to five stages defined in RCM process [28]:

- Selection of subsystem: maintenance competence management.
- Identification of component: defining the types of failure for each manufacturing resource and each competence, which has a considerable influence on reliability (stages 1-3, Figure 1).
- Analysis: defining the importance of each competence for the repair of each type of failure (stage 4, Figure 1).
- Optimal maintenance strategy selection: defining the "state of nature" and the implementation of maintenance expert selection map (stages 5-6, Figure 1).
- Analysis: the selection of this employee to repair a given resource, who guarantees an increase in the reliability level of a given manufacturing resource.

Each stage of the proposed approach must be formalised so that it can be computerised according to the Industry 4.0 concept.

The construction of the proposed approach is possible due to the acquisition and gathering of knowledge from the database of the information systems implemented within a company (stages 1–2, Figure 1) and the unique knowledge of employees performing activities in the maintenance department (stages 3–4, Figure 1). However, for acquired expert knowledge, so-called, to be useful, it needs to be represented and codified by data with a specified format. Accordingly, it is stated, at each stage of our approach, knowledge is defined, then acquired, and, finally, is then stored. Acquired knowledge must be converted into extracted and explicit knowledge, so that it can be computerised. This can be done [29] by using the frames based systems [30], frame logic [31], semantic networks [32], and conceptual graphs, with these being methods based on concept dictionaries, viz., ontologies [29], and methods that are based on established rules. The rule-based method was selected in order to create a formalised base for the approach (Figure 1).

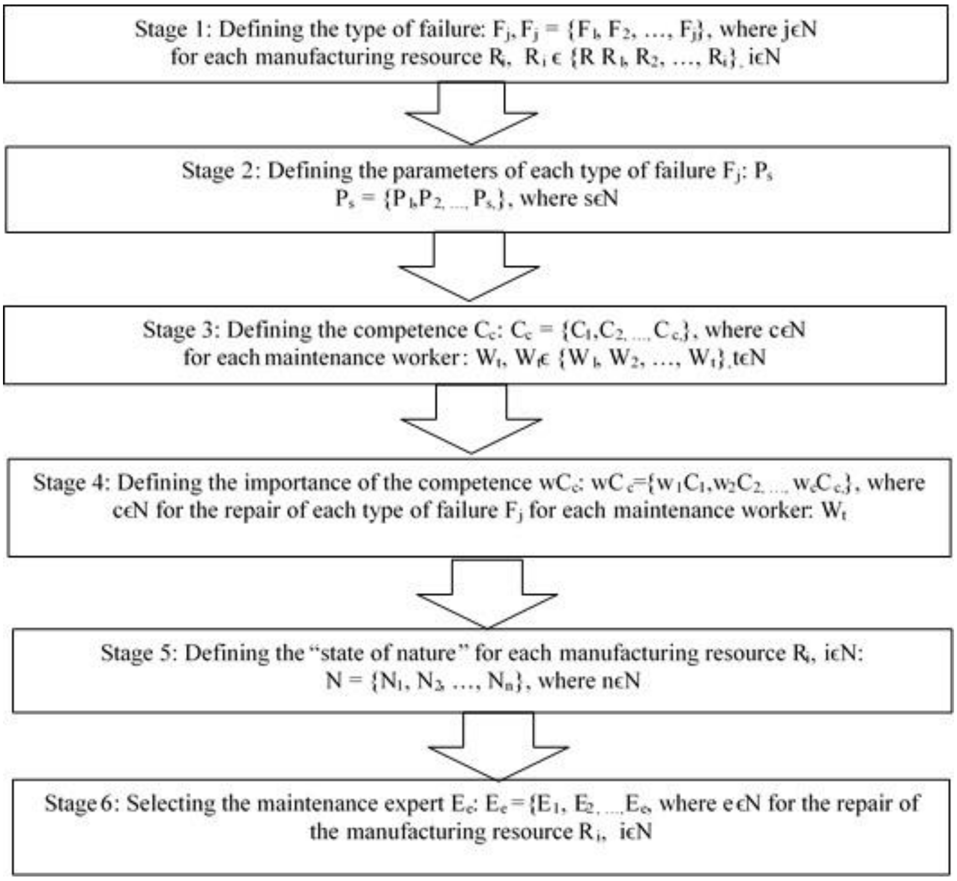

Figure 1. The proposed approach.

Stages one to four were based on the literature research results [4,24,33–35] and empirical research results [36] from the maintenance departments of manufacturing companies. In stage 1, (Figure 1) the types of failure for each manufacturing resource R_i, $i \epsilon N$ are defined: $F = \{F_1, F_2, \ldots, F_5\}$ (Table 1), where:

- F_1—failure of the control system.
- F_2—failure of the power system.
- F_3—failure of the cooling system.
- F_4—failure of the hydraulic system.
- F_5—failure of the material transfer system.

Table 1. Types of failure for each manufacturing resource.

Manufacturing Resources/Type of Failure	F_1	F_2	F_3	F_4	F_5
R_1	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$
R_2	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$
R_3	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$
…	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$
R_i, $i \epsilon N$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$	$1 \vee 0$

The rule for formalising the acquired data from the information system implemented, is defined in Table 1: If there is a failure in the manufacturing resource then the value of Fj = 1, if not Fj = 0, j = 1, ... , 5.

In stage 2, (Figure 2) the following parameters of each type of failure F_j, j = 1, ... , 5 for each manufacturing resource: R_i, i,jϵN are defined: P = {P_1, P_2, P_3} (Table 2), where kϵN

- P_1—time for diagnosing and finding the solution.
- P_2—maintenance operation time.
- P_3—time for testing.

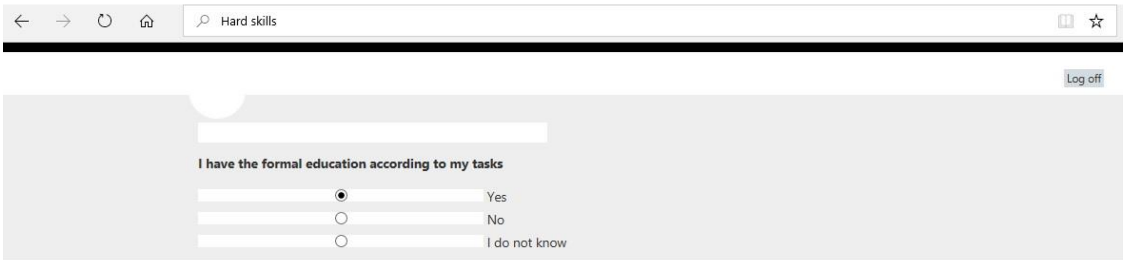

Figure 2. An extract from the web questionnaire, for employees facilitating the determining of competence: hard skills.

Table 2. The formalised data of parameters of each type of failure.

Parameters of Each Type of Failure	Description	Rules for Determining the Value of Parameters
P_1 – time for diagnose and finding solution	P_1 ϵ <10;30> [min]	if P_1 ϵ <10;15) [min] then P_1 = 1point if P_1 ϵ <15;20) [min] then P_1 = 2points if P_1 ϵ <20;25) [min] then P_1 = 3points if P_1 ϵ <25;28) [min] then P_1 = 4points if P_1 ϵ <28;30> [min] then P_1 = 5points
P_2 – maintenance operation time	P_2 ϵ <30;210> [min]	if P_2 ϵ <30;50) [min] then P_2 = 1point if P_2 ϵ <50;90) [min] then P_2 = 2points if P_2 ϵ <90;120) [min] then P_2 = 3points if P_2 ϵ <120;180) [min] then P_2 = 4points if P_2 ϵ <180;210> [min] then P_2 = 5points
P_3 – time for testing	P_3 ϵ <20;30> [min]	if P_3 ϵ <20;23) [min] then P_3 = 1point if P_3 ϵ <23;25) [min] then P_3 = 2points if P_3 ϵ <25;26) [min] then P_3 = 3points. if P_3 ϵ <26;28) [min] then P_3 = 4points if P_3 ϵ <28;30> [min] then P_3 = 5points

The rules for formalising the acquired data from the information system implemented is defined (Table 2):

In stage 3, (Figure 1) the competences of each maintenance worker: W_t, W_tϵ {W_1, W_2, ... , W_t}, tϵN are defined: C = {C_1, C_2, C_3, C_4, C_5}, where:

- C_1—Hard skills.
- C_2—Knowledge-based.
- C_3—Methodical.
- C_4—Soft Skills.
- C_5—Experience.

Assessing workers' knowledge is not an easy task; moreover, the quality and scope of this knowledge is crucial to it being able to be repeatedly used. The following method for assessing knowledge has been distinguished [37]: questions with a defined set of choices [38,39], rating grids or rules [40], questions with open answers [41], and questions regarding domain variables [42]. In the proposed approach, the sub-model for selecting workers, based on their competences, is developed (Table 3).

Table 3. The competence of each maintenance worker.

Competence	Description	Rules for Determining the Value of Competence
Hard skills (C_1) [34]	Completed engineering studies, references, certificate, certificate for the completion of specialised training in the handling of resources: R_i, where i϶N,	If a worker has no references, or has not completed engineering studies and possesses neither a certificate nor a certificate for the completion of specialised training, then C_1 = 0points. If a worker has references, but has not completed engineering studies, has no certificate and has no certificate for the completion of specialised training, then C_1 = 1point. If a worker has completed studies but has neither references, nor a certificate nor a certificate for the completion of specialised training, then C_1 = 2points If the worker has completed engineering studies and has references but has neither a certificate nor a certificate for the completion of specialised training, then C_1 = 3points. If the worker has completed engineering studies, has references and also has a certificate but has no certificate, for the completion of specialised training, then C_1 = 4points. If the worker has a certificate for the completion of specialised training, then C_1 = 5points.
Knowledge-based (C_2) [24,35]	A 15-question test about resources: R, where i϶N	If up to 7 answers are correct, then: C_2 = 0points. If 7–8 answers are correct, then C_2 = 1point. If 9 answers are correct, then C_2 = 2points. If 10–11 answers are correct, then C_2 = 3points. If 12–13 answers are correct, then C_2 = 4points. If 14–15 answers are correct, then C_2 = 5points.
Methodical (C_3) [35,36]	A 15-question test about comparing and classifying information and the use of available resource: R_i, wherei϶N	If up to 7 answers are correct, then: C_3 = 0points. If 7–8 answers are correct, then C_3 = 1point. If 9 answers are correct, then C_3 = 2points. If 10–11 answers are correct, then C_3 = 3points. If 12–13 answers are correct, then C_3 = 4points. If 14–15 answers are correct, then C_3 = 5points.
Soft Skills (C_4) [4,34]	A 15-question test about the ability to organise work, the ability to work in a team, communication skills and the ability to undertake task-oriented work and working under pressure	If up to 7 answers are correct, then: C_4 = 0points. If 7–8 answers are correct, then C_4 = 1point. If 9 answers are correct, then C_4 = 2points. If 10–11 answers are correct, then C_4 = 3points. If 12–13 answers are correct, then C_4 = 4points. If 14–15 answers are correct, then C_4 = 5points.
Experience (C_5) [24]	Number of years in the current company (L) Number of years, generally, in the profession (Z)	If $L \leq 3$ years and $Z \leq 3$ years, then: C_5 = 0points. If $L \leq 3$ years and $3<Z\leq 5$ years, then C5 = 1point. If $3<Z\leq 5$ years and $5<Z\leq 8$ years, then C_5 = 2points. If $5<Z\leq 8$ years and $8<Z\leq 10$ years, then C_5 = 3points. If $8<Z\leq 10$ years and $Z>10$ years, then C_5 = 4points. If $Z>10$ years and $Z>10$ years, then C_5 = 5points.

For each resource, R_i, where i϶N, the value of each competence for each worker is determined according to the rules (Table 3).

In the fourth stage, the Fuzzy Analytic Hierarchy Process (FAHP) was implemented. It was possible to determine the relative predominance of a particular factor of the core-competence model, from those elements of the framework that could not be calculated using FAHP; furthermore, it was possible to evaluate these factors; therefore, this means that the importance of competence for the repair of each type of failure Fj for each maintenance worker: W_t, $W_t \epsilon \{W_1, W_2, \ldots, W_t\}$, t϶N is defined. According to Nydick and Hill, a fuzzy number $\widetilde{a} = (l, m, u)$ with a triangular fuzzy-membership function can describe a linguistic variable. The triangular fuzzy number is defined in the set $[l, u]$ and its membership function takes a value that is equal to 1 at point m. The fuzzy scale of preferences is strictly defined by [43]. Maintenance managers assess the validity of each competence for the purpose of repairing a given machine:

- C_1—equally important, or moderately more important, or of greater importance, or of the most importance, compared with C_2 or with C_3 or with C_4 or with C_5.
- C_2—equally important, or moderately more important, or of greater importance, or of the most importance, compared with C_1 or with C_3 or with C_4 or with C_5.
- C_3—equally important, or moderately more important, or of greater importance, or of the most importance, compared with C_1 or with C_2 or with C_4 or with C_5.
- C_4—equally important, or moderately more important, or of greater importance, or of the most importance, compared with C_1 or with C_2 or with C_3 or with C_5.
- C_5—equally important, or moderately more important, or of greater importance, or of the most importance, when compared with C_1 or with C_2 or with C_3 or with C_4.

The importance of each competence C_c, $c\epsilon N$ for the repair of each type of failure F_j, $j\epsilon N$ for each maintenance worker: W_t, $t\epsilon N$, is determined while using the FAHP method: wC: $wC = \{w_1C_1, w_2C_2, w_3C_3, w_4C_4, w_5C_5\}$.

In the fifth stage, the "state of nature" N_{Ri}: $N = \{N_1, N_2, \ldots, N_{Ri}\}$, $i\epsilon N$ for each manufacturing resource R_i, $i\epsilon N$, is defined (Table 4), according to the formula:

for each W_t, $t \in N$
$NRi \equiv \frac{w_1C_1+w_2C_2+w_3C_3+w_4C_4+w_5C_5}{\bar{P}1+\bar{P}2+\bar{P}3}$, where $i\epsilon N$ and, $s = \{1,2,3\}$ means the average time of the all-time measurements.

Table 4. The value of each "state of nature" for each manufacturing resource R_i, $i\epsilon N$.

Workers/"State of Nature"	$\mathbf{N_{R1}}$	$\mathbf{N_{R2}}$	…	$\mathbf{N_{Ri}}$ **iϵN**
W_1	$N_{R1W1}\epsilon\langle 0;1.66\rangle$	$N_{R2W1}\epsilon\langle 0;1.66\rangle$	…	$N_{RiW1}\epsilon\langle 0;1.66\rangle$
…	…	…	…	…
W_t, tϵN	$N_{R1Wt}\epsilon\langle 0;1.66\rangle$	$N_{R2Wt}\epsilon\langle 0;1.66\rangle$	…	$N_{RiWt}\epsilon\langle 0;1.66\rangle$

The higher the value of the "state of nature" ($maxN_{Ri} = 1.66$), the greater is the certainty that the selection of this employee, to repair a given resource, guarantees an increase in the reliability level of a given manufacturing resource.

Our approach (stages 1-4) is partly investigated in the form of a web-application; this is presented below and it is based on a case study.

4. A Model for Supporting the Selection of Maintenance Experts

In order to illustrate the possibility of answering our research questions, let us consider the situation. The problem that is being considered entails selecting employees with the appropriate competence to undertake the repair of the given machine in companies, involving Industry 4.0. The research was carried out in the automotive industry company. Production, being partly automated, is carried out using a two-shift system. The maintenance manager supervises the work of four employees who service 18 machines. Below is an extract from the web-application for identifying the Industry 4.0, maintenance expert, based on the approach (Figure 1).

According to stage 1, (Figure 1) the data on the types of failure for each manufacturing resource from the information system is received and formalised, according to the rules that are included in Table 1 (Table 5)

Then, according to stage 2, the formalised data of the parameters of each type of failure (Table 2) is identified (Table 6).

According to the third stage, for each competence: C_1, C_2, C_3, C_4, C_5, a knowledge web-questionnaire is defined. The extracts from the web-questionnaires for workers facilitating the obtaining of values for each competence are presented (Figures 2–5).

Table 5. Data about the types of failure for each manufacturing resource.

Manufacturing Resources/Type of Failure	F_1	F_2	F_3	F_4	F_5
R1	1	1	1	1	1
R2	1	1	1	1	1
R3	1	1	1	1	1
R4	1	1	0	1	0
R5	1	1	0	1	0
R6	1	1	0	0	0
R7	1	1	1	0	0
R8	1	1	1	0	1
R9	1	1	1	0	1
R10	1	1	0	1	1
R11	1	1	1	1	1
R12	1	1	0	1	1
R13	1	1	0	1	0
R14	1	1	0	1	0
R15	1	1	0	0	0
R16	1	1	1	0	0
R17	1	1	1	0	1
R18	1	1	0	1	0

Table 6. Parameters of failure: F1—failure of the control system.

F_1 – Failure of Control System	F_{11}			F_{12}			F_{13}			F_{14}		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
R1	13	56	21	26	183	25	18	203	23	30	122	26
R2	15	104	22	11	71	20	23	102	24	18	145	25
R3	20	51	23	14	107	28	10	60	21	26	66	29
R4	15	182	24	27	100	30	24	117	28	20	45	24
R5	29	106	30	18	174	24	30	208	27	22	196	28
R6	18	102	23	20	150	22	26	76	20	20	149	20
R7	26	65	22	23	203	20	27	209	30	14	41	30
R8	13	203	25	17	51	22	29	116	28	17	107	29
R9	21	169	20	27	55	20	13	187	25	24	114	27
R10	19	202	24	25	139	26	27	166	24	20	81	23
R11	15	195	20	28	163	23	22	152	20	11	157	21
R12	29	53	22	19	159	25	29	163	21	15	188	21
R13	28	174	27	22	198	20	12	188	21	21	103	25
R14	14	158	27	25	61	22	14	132	23	29	188	26
R15	29	30	30	14	80	28	26	105	21	24	99	27
R16	14	30	23	17	52	30	16	168	21	28	41	30
R17	25	206	28	19	84	25	13	51	25	15	193	22
R18	11	106	23	17	50	26	17	91	28	27	115	27

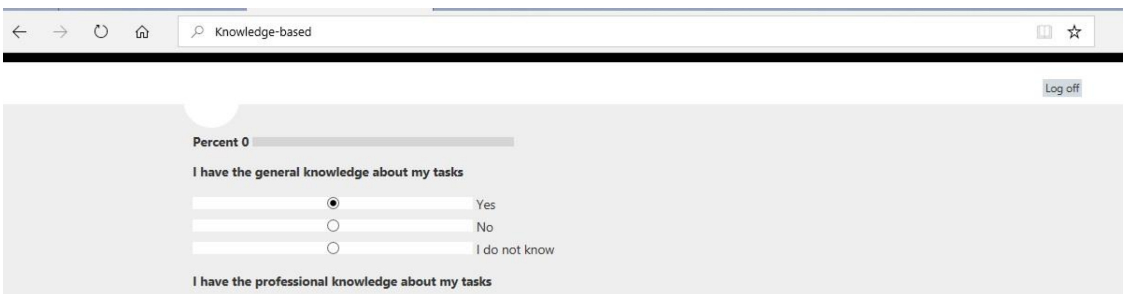

Figure 3. An extract from the web questionnaire, for employees facilitating the determining of competence: knowledge-based.

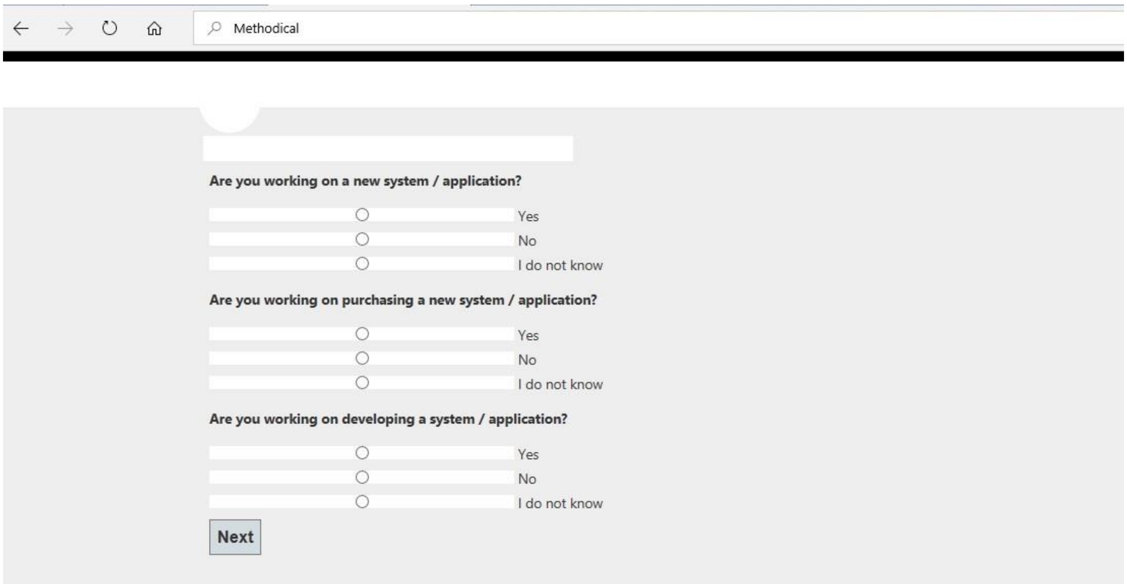

Figure 4. An extract from the web questionnaire, for employees facilitating the determining of competence: methodical.

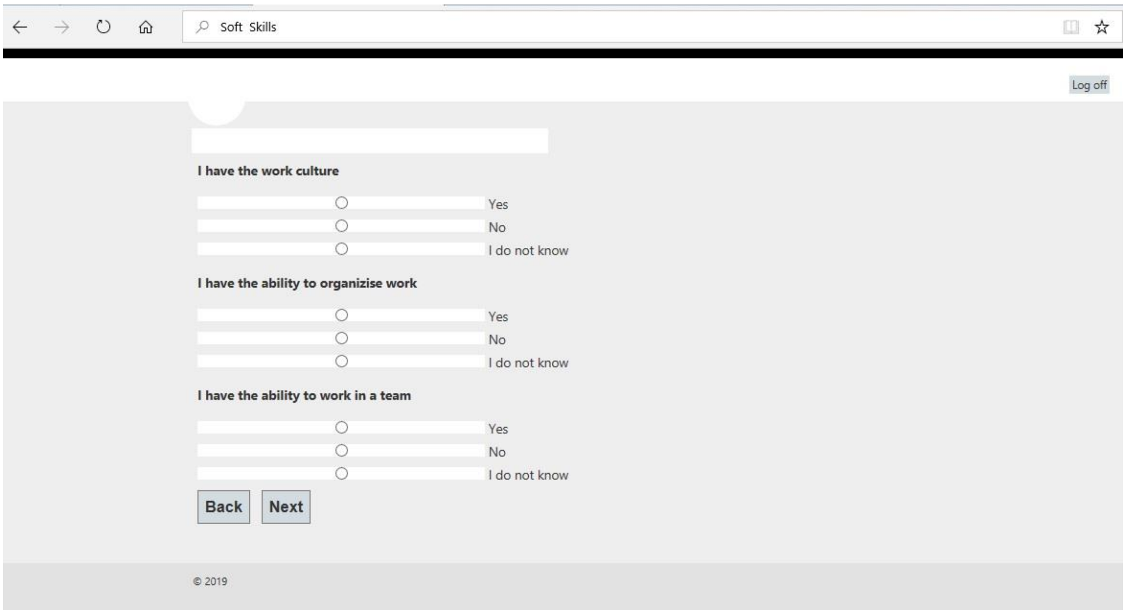

Figure 5. An extract from the web questionnaire, for employees facilitating the determining of competence: soft skills.

Each of the four employees completed the web-forms of questionnaires and, based on their responses as well on the rules included in the Table 3, the following values of each competence for each worker are received (Table 7).

Table 7. The values of competence for each maintenance worker.

Workers/the Values of Competence	C_1	C_2	C_3	C_4	C_5
W_1	2	2	4	1	1
W_2	1	1	3	3	1
W_3	2	1	5	0	0
W_4	1	2	4	1	1

According to the fourth stage, the FAHP method was implemented and used. The fuzzy weightings matrix of competences for the repair of each defined failure—see Table 8 as the example for the F1—failure of control system.

Table 8. The values of elements of the comparison matrix, using the Fuzzy Analytic Hierarchy Process (FAHP) method as the example for the F_1—failure of control system.

Competence	C_1	C_2	C_3	C_4	C_5
C_1	(1,1,1)	(1/3,1,1)	(3,5,7)	(3,5,7)	(3,5,7)
C_2	(1,1,3)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)
C_3	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	(1/5,1/3,1)
C_4	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(1/3,1,1)
C_5	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	(1,1,3)	(1,1,1)

Using the FAHP method, the importance of the each competence for the repair of the defined failure F_1 was obtained, respectively:

- The importance of C1: w1 = 0.4014.
- The importance of C2: w2 = 0.3429.
- The importance of C3: w3 = 0.1060.
- The importance of C4: w4 = 0.0904.
- The importance of C5: w5 = 0.0593.

Accordingly, for each of the four employees, the following values for each competence, dedicated to the F1 (failure of the control system), were obtained (Table 9).

Table 9. The values of the competence of each maintenance worker.

The Importance of Competence	w_1C_1	w_2C_2	w_3C_3	w_4C_4	w_5C_5
W_1	0.8028	0.6858	0.424	0.0904	0.0593
W_2	0.4014	0.3429	0.318	0.2712	0.0593
W_3	0.8028	0.3429	0.53	0	0
W_4	0.4014	0.6858	0.424	0.0904	0.0593

According to the fifth stage, the values of each natural state for each manufacturing resource R18 for the F_1 (failure of control system) were defined. Table 10 presents the formalised data from Table 6.

Accordingly, based on the data from Tables 9 and 10, the "states of nature" values are received (Table 11).

Table 10. The values of the parameters for each manufacturing resource R18 for the F1 - failure of control system.

e Employees/ Manufacturing Resource	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}
W_1	4	6	7	9	13	7	7	9	8	9	8	8	14	10	11	4	14	6
W_2	12	4	9	12	8	8	9	5	7	12	11	9	9	5	8	9	7	8
W_3	9	8	4	11	14	7	14	13	9	11	8	10	7	7	8	7	6	10
W_4	13	9	11	6	13	8	7	10	10	7	6	8	9	14	10	11	8	11

Table 11. The values of the "states of nature".

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}
W_1	0.5156	0.343717	0.294614	0.229144	0.158638	0.294614	0.294614	0.229144	0.257788	0.229144	0.257788	0.257788	0.147307	0.20623	0.187482	0.515575	0.147307	0.343717
W_2	0.116067	0.3482	0.154756	0.116067	0.1741	0.1741	0.154756	0.27856	0.198971	0.116067	0.126618	0.154756	0.154756	0.27856	0.1741	0.154756	0.198971	0.1741
W_3	0.186189	0.209463	0.418925	0.152336	0.119693	0.239386	0.119693	0.1289	0.186189	0.152336	0.209463	0.16757	0.239386	0.239386	0.209463	0.239386	0.279283	0.16757
W_4	0.127762	0.184544	0.150991	0.276817	0.127762	0.207613	0.237271	0.16609	0.16609	0.237271	0.276817	0.207613	0.184544	0.118636	0.16609	0.150991	0.207613	0.150991

The "state of nature" means the relation of the competence level of a given employee, whose validity has been correctly assessed for the purpose of repairing a given resource in the enterprise, as compared to the time that is taken to repair a given resource. The following rules for the definition of the "maintenance expert selection map" are defined:

for $N_{RiWt} \epsilon (1.2;1.66>$ very strongly recommended for the repair of a given resource

for $N_{RiWt} \epsilon (0.8.;1.2>$ strongly recommended for the repair of a given resource

for $N_{RiWt} \epsilon (0.5;0.8>$ recommended for the repair of a given resource

for $N_{RiWt} \epsilon (0.27;0.5>$ weakly recommended for the repair of a given resource

for $N_{RiWt} \epsilon <0;0.27>$ not recommended for the repair of a given resource

Table 12 presents the "maintenance expert selection map" that is based on the value of the "States of nature" (Table 11).

Table 12. The "maintenance expert selection map".

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}	R_{18}
W_1																		
W_2																		
W_3																		
W_4																		

Hence, the maintenance expert remains undefined in our case study, since no "state of nature" has been marked in red. The maintenance manager received support to select W_1 to repair resources R_1 and R_{16}, W_2 was selected to repair resources R_2,R_8 and R_{16}, W_3 was selected to repair resources R_3, and R_{17}, W_4 was selected to repair resources R_4 and R_{11}. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

5. Discussion

The proposed approach makes it possible to identify the competences of maintenance department employees and it also makes it possible to give them validity to assign repair work correctly, depending on the type of failure.

The model also assumes that data is obtained regarding the repair times of a given machine, from IT systems that the enterprise has implemented. Thanks to such defined elements, it is possible to define the so-called "state of nature" for each enterprise resource vis-à-vis each employee. The higher the value of a given natural state (max = 1.66), the better the matching of a given employee, to a given failure, on a given resource. In addition, formalisation rules were used for each element in the proposed approach in order to implement the IT system. The proposed solution allows for maintenance managers to increase the availability of the resources of the enterprise.

Quantitatively defining the competences of employees in our research was a particularly difficult task.

Therefore, formalisation rules were strictly defined for each type of competence, with the IT implementation of the given approach then being presented.

The use of the proposed approach allows for decision making to be supported when selecting an expert with the best ratio of competences, in relation to the time that is required to repair a failure in a given resource. The use of the maintenance expert selection map is helpful in:

- Selecting a maintenance expert, from among available employees, to repair a given resource.
- Selecting the scope of employee training, in order to improve the competences of employees in relation to the effective repair of resources, by shortening the elimination time of failures and by reducing the downtime of failures.

- Defining a motivating system for all maintenance workers based on the value of natural states.

The proposed approach is currently implemented in the form of a decision support system when selecting the most effective maintenance employees for repairing failures in manufacturing resources. The current implementation work has been partly completed in the form of a web-application, related to the definition of competences. The five competence questionnaires were defined and implemented. This application also implemented the FAHP method. Our web-application will be extended by the algorithm for automatic data, for the repair times of each failure and also extended by the acquisition and automatic creation of a maintenance expert selection map as part of further research.

6. Conclusions

In the research presented, an innovative approach to selecting expert workers in a maintenance department is created, in part, also in the form of a web-application. The “maintenance expert selection map" innovation, so-called, provides the formal procedures for describing the competences of each maintenance worker and defining the best “state of nature”. It was established that the “maintenance expert selection map” is useful in:

- Describing the competence of workers.
- Delecting workers according to competence for repairing a given manufacturing resource.
- Determining the scope of employee training.

In sustainable manufacturing, the right employee, with the proper competence and being employed in the right workplace is crucial [33]. The proposed approach can help to increase the sustainability of the company in all three of its dimensions:

- Economic and environmental—the proposed approach allows for managers to assign a particular worker to repair a given resource; selecting this worker will guarantee the maximum availability of the manufacturing resource. The right assignment of highly-qualified maintenance staff to repair a resource results in lower downtime costs, lower additional costs due to defective products, and a reduction in the risk of the possibility of total damage and of the risk of loss of warranty.
- Social—the proposed approach allows not only for the core competences to be determined, but also the need for new competences and the demand for training programmes for low-qualified maintenance department workers. By using the proposed approach, the manager may decide to assign a given employee to a place of work that is more appropriate to his or her qualifications, which will ultimately translate into the achievement of better working conditions.

We are planning to expand the approach with the dynamic measurements idea in our further works [44,45]. In the next stage, a method for inspection for the obtained improvement of availability of the manufactured resource thanks to the use of the proposed “maintenance expert selection map" will be developed. Subsequently, the model for updating the assessment of availability based on the formulation of additional events, which may affect the extension of the repair time of the resource, regardless of the competences of the employees, will be established.

Although this study is an attempt at dealing with the several aspects of decision making, to be supported when selecting an expert with the best ratio of competences, there are still some limitations, which could be considered in future research.

Firstly, there is the limitation in creating a standard for our approach to supporting the selection of maintenance experts, namely, the development of an application. Secondly, there may be some limitations when it comes to providing integration with the CBM standard for developing the application of open-software, since no standard currently exists. Thirdly, the approach should be a prominent inscribed feature in the company’s development strategy and it should also be part of the evaluation of employees and the system by which they are motivated.

The proposed “maintenance expert selection map" approach will be useful for maintenance department managers and will allow them to define not only core competences, but also to enjoy maximum availability regarding manufactured resources and preparing training programmes that are adequate to the needs both of current and of new employees, despite the above limitations.

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