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# MAINTENANCE – IDENTIFICATION AND ANALYSIS OF THE COMPETENCY GAP

# UTRZYMANIE RUCHU – IDENTYFIKACJA I ANALIZA LUKI KOMPETENCYJNEJ*

*The efficiency of maintenance processes in an enterprise largely depends on ensuring adequate resources for its implementation. The main factor that affects the quality of these processes is competent employees. Their knowledge, skills and ability to respond to unexpected situations largely determine the efficiency of the functioning of the technical infrastructure in an enterprise. In the light of the prospects for the development of the Industry 4.0 concept, and, thus, for the development of highly automated systems, the demand for qualified maintenance employees will increase. Therefore, in order to ensure the right level of competency of maintenance workers, through the proper assessment and identification of their competency gap, is an important task of managers. In many enterprises this is not implemented. The aim of the presented work was to developed a comprehensive model of the competency assessment of maintenance workers. The implementation of the developed model enables the identification of the current level of employees' competencies and identification of the competency gap, as well as it allows to assess the effects of a failure to meet the required level of competency. Additionally, the results of the identification of the real activities taken by the surveyed enterprises concerning the competency assessment of maintenance services employees are presented in this article. The study was carried out in manufacturing enterprises in different industries on a specific area. The results were analysed and presented in a graphic form.*

***Keywords**: maintenance management, exploitation efficiency, workers competency, competency gap.*

*Efektywność działań utrzymania ruchu w przedsiębiorstwie w dużej mierze zależy od zapewnienia odpowiednich zasobów do jego realizacji. Podstawowym czynnikiem, który ma wpływ na jakość realizacji tych działań są kompetentni pracownicy. Ich wiedza, umiejętności i zdolności reagowania na nieprzewidziane sytuacje, w dużej mierze decydują o sprawności funkcjonowania posiadanej infrastruktury technicznej w przedsiębiorstwie. W świetle perspektyw rozwoju koncepcji Przemysł 4.0, a tym samym rozwoju wysoce zautomatyzowanych systemów, wzrośnie zapotrzebowanie na wykwalifikowanych pracowników utrzymania ruchu. Dlatego ważnym zadaniem menedżerów przedsiębiorstw jest zapewnienie właściwego poziomu kompetencji pracowników utrzymania ruchu, poprzez ich odpowiednią ocenę i identyfikację luki kompetencyjnej, co w wielu przedsiębiorstwach nie jest realizowane. Celem przedstawionej pracy było opracowanie kompleksowego modelu oceny kompetencji pracowników utrzymania ruchu. Zastosowanie opracowanego modelu umożliwi identyfikację aktualnego poziomu kompetencji pracowników, identyfikację luki kompetencyjnej, jak również pozwoli ocenić skutki niezapewnienia wymaganego poziomu kompetencji. Dodatkowo w pracy przedstawiono wyniki badań, których celem było zidentyfikowanie rzeczywistych działań realizowanych w przedsiębiorstwach w zakresie oceny kompetencji pracowników służb utrzymania ruchu. Badania przeprowadzono w przedsiębiorstwach produkcyjnych, w różnych branżach przemysłu na określonym obszarze. Wyniki badań opracowano i przedstawiono w postaci graficznej.*

***Słowa kluczowe**: utrzymanie ruchu, efektywność eksploatacji, kompetencje pracowników, luka kompetencyjna.*

## 1. Introduction

The present activities of designing and installing of production systems are directed towards the increase of their efficiency, flexibility and changeability. It is particularly visible in the time of the Industry 4.0 concept development, which requires from enterprises to implement IT technologies in production areas. It forces the use of more and more sophisticated and complex solutions including technological or organizational solutions connected to the data collection and analysis, technology development, the ability to react fast to both internal and external changes and improvement of current activities [9, 14, 18, 33].

Technologies production systems development is related to the necessity of introducing changes in the work organization and environment [11]. This issue is particularly essential from the point of view of ensuring the right level of maintenance activities. The result of their wrong realization are sudden interruptions in the process of production or services realization what often put enterprises at risk of tremendous financial loss [27, 28].

In the literature, some works which assess perspectives of maintenance services functioning in the context of fast industrial development can be found. Many works underline the need of ensuring the right level and the development of workers' competencies in machine maintenance. In the work [25] a wide analysis of the perspectives of the maintenance development was performed. The analysis was divided into three main areas: the basis of maintenance, technological challenges for the future and maintenance in the 4.0 Industry concept. The analysis allowed to identify certain challenges such as planning maintenance on the system level, interoperability, IT safety and long-term data management in the whole period of exploitation. Summing up, the author stressed that a new technology may influence the decrease of human errors, although the cooperation between „a human being and a machine" in exploitation activities is important. Additionally, in the works [12, 21], it was assumed that maintenance workers will need in the nearest future new skills, which will allow for effective use of new technologies and proper realization of an exploitation process with highly automated and complex systems. It will require adequate education and trainings on many levels.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

In the work [3] scenarios of the functioning of the future maintenance in the production realization in the times of 4.0 concept were developed. The study of scenario planning was based on the Delphi method, examining 34 forecasts concerning potential changes in the internal and external environment of the maintenance organization. Among the analysed forecasts, the need of developing maintenance workers' competencies was also found. The author underlines that in order to keep up with the technological development, crucial competencies of the workers in maintenance should be ensured. The author described high probability of the necessity of the management of the future competencies, new requirements concerning competencies, education and trainings related to the possibility of changing a competencies profile. He stresses that the management should be aware of the fact that not providing the right level of competencies is related to an ineffective maintenance process, what in turn increases susceptibility to interruptions, decreases reactions to failures and, at the same time, decreases the competitiveness of an enterprise.

Thus, there is a need of workers' educating and training as well as of the development of a new innovative method of competencies management such as e.g. competencies models, assessment and monitoring skills, using the best experience-based practices and IT tools.

## 2. The role and assessment of competencies of the workers

A competency is a combination of three elements: knowledge, skills and attitude. They distinguish a particular person who in an efficient, effective and answering the quality expectations way realizes the tasks assigned him/her. For the assessment of the used competencies there are many models which can be classified into the following five categories [13]: quantity measures (such as tests, questionnaires, interviews or regular observations), descriptions, comparative analyses, simulation methods and research method related directly to his/her person and work environment. Competency models are developed in order to assess the level and range of the acquired competencies and they provide the possibility of identifying the areas in which these competencies should be complemented [21]. As underlined in the works [6,7], the assessment of competencies is a process of obtaining proofs and the level of competencies among people dealing with the tasks based on certain standards. The adequate competency model, for the certain area, is the one which allows to determine the levels of all the needed competencies and, additionally, indicate expressly the areas for improvement. Such a model should be exact, reliable, should not assess the level of competencies, skills and the worker's efficiency. It is especially important for the assessment of technical competencies, e.g. in the area of machines maintenance, among which one should assess professional knowledge, knowledge about activities, skills as well as the ability to make decisions on one's own [22].

The process of the development and assessment of competency is time consuming and expensive. What's more, appointing workers to a dedicated training is not always possible. This problem is particularly essential for small and medium enterprises. That's why it is important to know which competencies are available or must be developed [1].

In the literature the problem of competency assessment in different areas is described widely, e.g. in production areas [2, 10, 19, 32]. Only a few examples of the works concerning this topic can be found within competency in maintenance.

In the work [29] the authors perform the review of the assessment of skills in maintenance. The authors, through this assessment, describe strengths and weaknesses of a given worker or a given group of workers. For this assessment they propose the use of survey questions. The analysis of the assessment results obtained in this way allows to identify the gap, describe the skills needed for the effective work performance and determine a trainings schedule. The works [5, 17] present the use of a competency matrix for the assessment of a level of maintenance workers, as well as the activities realized in the autonomous machine maintenance in the Total Productive Maintenance (TPM) for operators.

In the literature, the issues on the assessment and skills enhancement of the technical service workers as well as the realization of planes maintenance operations are mentioned. In the work [4] a method of e-learning trainings in increasing the qualifications of technical service workers was proposed. Furthermore, in the work [30] the problem of the selection of workers with adequate qualifications for the realization of particular tasks related to the process of plane repairing was presented.

However, the analysed works lack a complex model of the workers' assessment in the maintenance area, a model which would allow to assess the competencies on many levels of maturity and detail. Additionally, the perspectives of the development of the maintenance area point to the need of focusing on this issue.

In connection with the above, the problem of ensuring the right level and competency in a competency assessment in a maintenance process was undertaken.

## 3. The range and methodology of the study

This work was realized in two stages. In the first stage, the study concerning the identification of the activities realized by enterprises in the assessment of the maintenance (M) workers' competencies in the chosen enterprises from the podkarpackie voivodship was conducted. This stage was realized in the following steps:

1. Determining the range and area of the study.
2. Developing a study sheet.
3. Choosing enterprises for the study.
4. Conducting the study and analysing the results.

In the second stage, a methodology of maintenance workers' competencies assessment was proposed, and a detailed analysis as well as the possibilities of improving the assessment of workers' competencies from the randomly chosen enterprise with the use of the proposed model was conducted. This stage was realized as follows: developing a three-stage methodology of M workers' competencies assessment, choosing an enterprise, conducting the study, analysing of the obtained results, proposing changes. The detailed analysis of the obtained results was presented in the further part of this work.

## 4. Study results

### 4.1. The first stage of the study

#### 4.1.1. The area and realization of the study

In the first stage the study was conducted. It concerned the identification of real activities realized by the analysed enterprises in the assessment of the maintenance (M) workers' service competencies (MS). The following issues were analysed: Do the companies identify the needed competencies of M workers? Do they assess their fulfilment by the workers? Do they take any action in order to broaden or complement them? The study concerned production companies and was conducted on the specified geographical area (podkarpackie voivodship) (Poland). Within the realized study, the analysis covered the areas which directly result from the correctly performed process of the competencies assessment. This process, according to the approach presented in the work [26], should be based on the following steps:

1. Identification of the requirements for maintenance service workers.
2. Determining the demanded level of qualifications.

3. Conducting the competency assessment according to the specified requirements with the help of a specific method (e.g. an interview, observations).
4. Analysing the obtained results and undertaking further action.

The study covered the following issues:
– determining the competency requirements for particular maintenance positions/ jobs,
– analysing workers' competencies – the frequency and methods,
– completing/ broadening workers' competencies with basic or professional trainings,
– developing and functioning of the work instruction on maintenance positions/jobs.

50 enterprises were invited to take part in the study. The object of the study could include a production enterprise which possessed on its grounds functioning maintenance services regardless of their organisation, and the one implementing the Lean Manufacturing philosophy assumptions. The study was conducted in the form of interviews. The representatives of the medium and top level management and the workers directly responsible for the process of supervising machines and technological devices in the company, as well as the chosen maintenance workers took part in the study. The study took the form of conjunctive closed questions. For each question the level of fulfilment in the scale 0-10 was determined. Additionally, each respondent could add his/her own remarks and observations within the marking range.

### 4.1.2. The structure of the studied enterprises

The enterprises which took part in the study were classified according to the following criteria: industry, production type, capital type and its situation. Table 1 shows the structure of the studied enterprises.

45% (the most) enterprises are of an aviation industry, then 20% are automotive. The remaining industries include among other metal processing (10%), chemical, wood and paper (5%) and other (printing and electronics – 15%). Among the analysed enterprises medium and large batch production dominated (32%).

63% of them possessed major foreign capital, 26% were Polish capital companies and only 11% of them possessed major national capital. Most of the studied companies, that is 63%, describe their situation as developmental, 28% as stable and 11% as difficult.

### 4.1.3. Results of the study

According to the correctly realized process of the workers' competency assessment, the first step is to identify all requirements. These requirements are directly connected to the kind and range of the works realized by the workers in particular maintenance departments. However, it also results from the way maintenance departments are organized in an enterprise. The study examined what percent of the analysed enterprises identifies maintenance workers' competencies (Fig.1).

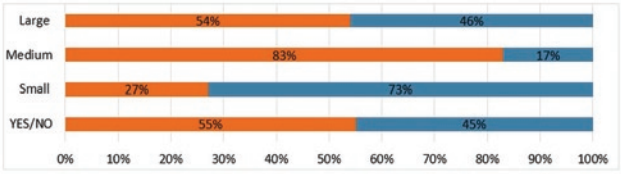


*Fig. 1. Identification of competencies in maintenance management in different size companies*

The study shows that 55% of the analysed companies determine maintenance workers' competencies. The most, that is 83% of the medium enterprises identify competencies, the least, because only 27%, small enterprises. Competencies for all the workers are identified by 50% of medium, 30% of large and only 20% of small enterprises (Fig. 2). The identification of competencies for the chosen workers is realized by small and medium enterprises, 40% each. For the most of workers, competencies are identified mainly by medium, then large and small enterprises, respectively 50%, 40% and 30%.

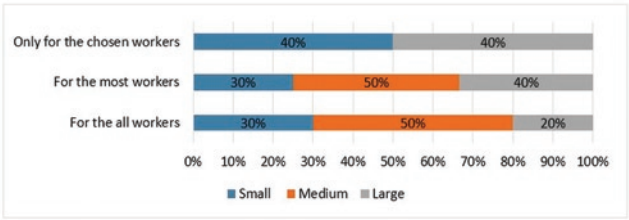


*Fig. 2. The range of the competency assessment*

The next, very important step, of the competency assessment process is the level of fulfilling the identified requirements by the maintenance workers. A periodical assessment of the workers among the analysed enterprises is realized by as much as 84% of them. The most is realized by all of the analysed medium enterprises, 90% of large and only 30% of small. The most commonly used for the competency analysis is a competency matrix (large and small enterprises) as well as a worker's assessment sheet together with the determined assessment criteria. Such an analysis is performed annually or every two years. About 75% of the companies, after the assessment, undertake activities aiming at broadening and supplementing competencies in the form of additional trainings. They are both internal trainings conducted by the company experts, and external trainings conducted by training companies. A detailed analysis of the results obtained is presented in Fig. 3.

*Table 1. The studied enterprises structure*

| Criterion | Studied enterprises structure | | | | | |
|---|---|---|---|---|---|---|
| Size | Small and micro | | Medium | | Large | |
| | 16% | | 21% | | 63% | |
| Industry | Aviation | Automotive | Metal processing | Wood and paper | Chemical | Other |
| | 45% | 20% | 10% | 5% | 5% | 15% |
| Production type | Piece | Small batch | Medium batch | Large batch | Mass | |
| | 18% | 9% | 32% | 32% | 9% | |
| Capital type | Total polish capital | | Major polish capital | | Major foreign capital | |
| | 26% | | 11% | | 63% | |
| Company's situation | Difficult | | Stable | | Developmental | |
| | 11% | | 28% | | 61% | |

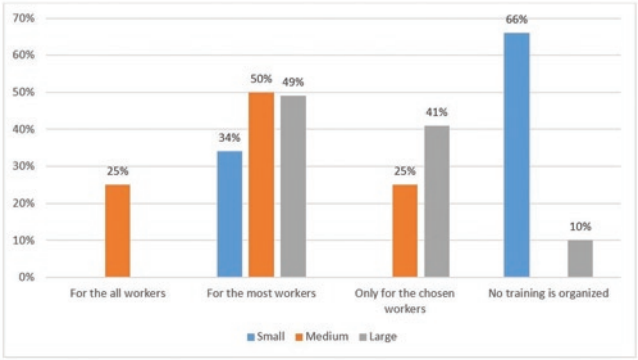


*Fig. 3. Improving worker's competencies*

The results, presented in Fig. 3, show that only 25% of the analysed medium companies improve competencies of all their workers. However, it is worth noting that although so few companies assess their workers' competencies, many of them undertake activities in order to improve them. The worst situation is in small enterprises.

#### 4.1.4. Discussion and the analysis of data after the first step

The study shows that 45% of the enterprises do not assess the competency of their workers who realize a maintenance process. The lack of a competency assessment handicaps significantly the analysis and the possibilities of discovering the so called staff shortages i.e. competency gaps. The lack of the workers with adequate competencies may influence on machine efficiency, which is dependent on, among others, the quality of the realized preventive and corrective activities. The study also shows that almost a half of the studied companies does not identify the maintenance workers' competencies. The study results demonstrate that it is worth examining this issue as well as making enterprises aware of the importance of the machine efficiency for the production realization. This efficiency is also the result of smoothly functioning and competent maintenance services. The study points that worst situation is in small enterprises. Because it is worth showing, especially to small enterprises, how to assess the competencies, the methodology of workers' competency assessment will be developed in the further part of this article.

## 5. The second stage of the study

### 5.1. Methodology of the workers' assessment in maintenance

The second stage of the study considered the development of the methodology of the maintenance workers' competency assessment (Fig. 4) and its verification in an enterprise. The developed methodology consists of three levels:

I Development of a competency matrix.

II Indicative assessment of the level of competency on the basis of competency matrix developed.

III Assessment of the risk of providing the level of competency.

On every level the methodology uses a different, sophistication diversified method of a competency assessment of the maintenance workers, starting from the simplest method – a competency matrix, through an indicative assessment method to the fuzzy logic. This solution will allow to combine comprehensively the methods already used in this area [17] as well as in the competency assessment of production workers [2], extending of intelligent methods, what makes a new consistent solution. The developed model enables the identification of the current level of workers' competency and competency gap as well as it allows to assess the effects of the failure to provide the required level of competency. While developing the methodology, the requirements of the competency assessment models presented in chapter 2 were taken into consideration.

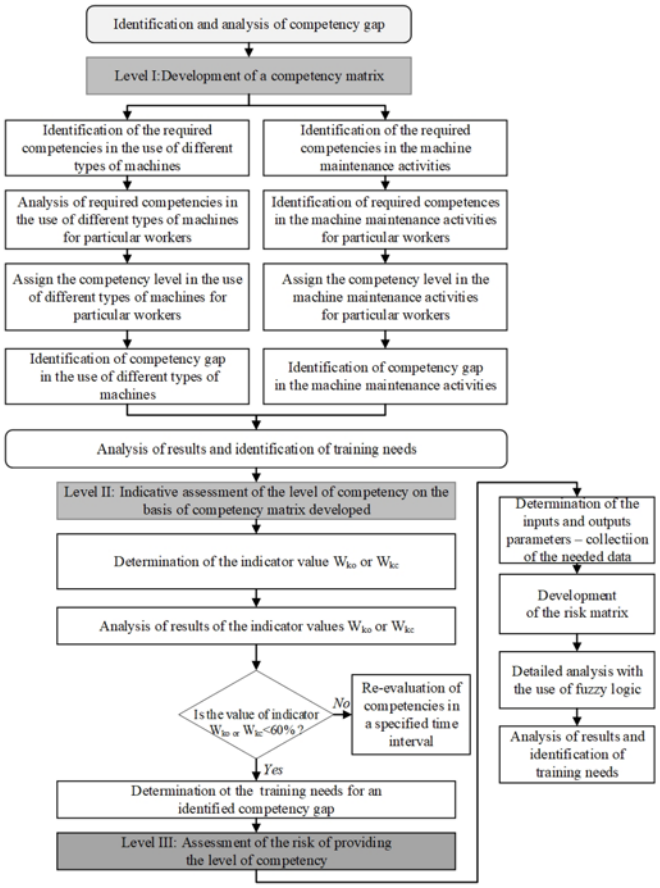


*Fig. 4. Methodology of the assessment of maintenance workers' competency*

The proposed methodology was used for the analysis and possibilities of improving the maintenance workers' competency assessment in a chosen enterprise.

### 5.2. Machine supervision activities in the analysed enterprise – a problem description

The first stage of the study proved that the process of maintenance service workers' competency assessment was the worst in small enterprises. That's why, a company of such a size was chosen for the further analysis. The studied production enterprise operates in a metal processing industry on the podkarpackie voivodship. The data collected by the author and the data from the work [20] were used for the analysis. The analysed company produces machine parts, as well as preparing steel structures. Additionally, it distributes steel products and industrial gases. Innovative products, timely execution of orders, highly qualified staff, efficient technical service and high quality as well as an individual approach towards the clients' needs have caused the company to be valued and trusted by its recipient.

In the analysed enterprise, several machines are supervised. They are both traditional as well as CNC machines. In most of the small enterprises, because of the small number of machines, maintenance service workers function as one-person position. In relation to this fact, machine operators are responsible for many activities connected to the current realization of autonomous activities on machines as well as maintenance activities. The situation is similar in the analysed

enterprise. The main supervision over machines is done by a maintenance specialist, whereas current maintenance activities are realized by operators.

The supervision over a machine park is conducted through inspections done in the guarantee period, the assessment of a machine condition before starting the work by an operator and through the continuous monitoring of its technical condition. Realization of activities within the machine supervision is carried out independently and partly due to external companies. Within the machines supervision the information related to their load and waiting time for service is collected. An operator and quality control worker are responsible for collecting these data. Downtimes connected to planned inspections are registered in an enterprise, whereas the information on machines failures in not registered. The activities undertaken in order to prevent unplanned downtimes include: autonomous and preventive service realization, machines modernization and ordering a part of maintenance and corrective activities to external companies.

The challenge for a chosen company is determining and the analysis of competency needs not only within the current maintenance of the possessed machines types, but also within the preventive maintenance. It is also essential because, the possessed machines play a minor or major role in a production process. Improper realization of a maintenance and preventive process on the positions, particularly those machines which are bottlenecks, causes unexpected failures, and, as a result, delays in orders realization as well as financial and image consequences for the company.

In this context, it is important for the workers who operate machines and realize basic preventive actions to possess the right qualifications. In connection to this, it is necessary to assess the competencies of maintenance workers. What's more, it is vital to possess formal attitudes in order to conduct a competency analysis in machine maintenance and the possibilities of determining a competency gap to minimize *ad hoc* assessments. The lack of formalization of such a process causes, that decisions may be wrong because they are not only undertaken on the basis of the existent data and information, knowledge or experience but also on the basis of intuition or intentions of the person doing the assessment.

## 5.3. Verification of the methodology of the workers' competency assessment in a chosen enterprise

### 5.3.1. Level 1: Development of a competency matrix

A competency matrix systematizes the level of knowledge and skills which are possessed by a worker in the specified area. It is successfully used to manage the process of production positions standardization as well as for the activities realized in the autonomous machine maintenance in TPM for operators [2, 5, 17]. For designing a competency matrix the following steps should be performed:

*1. Identification of requirements in maintenance.*

This step consists of the identification of the required competencies for the identified areas. A competency matrix is commonly designed for the realized activities. However, based on the author's experience concerning enterprises, it often occurs that maintenance workers are not only dedicated to the specific activities in machine supervision but also to the specific types of machines. That's why, in the presented model, it is proposed to determine workers' competencies in two areas: for the specific types of the supervised machines and for the identified activities.

*2. Identification of competencies for particular workers.*

This step requires the assessment of the fulfilment of the required competencies for every worker. Determining the competencies should be realized for particular workers according to the established requirements and areas (machine types and activities) identified in step 1.

*3. Assigning competency levels.*

Levels of competency determine the level of knowledge and skills in the analysed area. The proposed levels of competency developed on the basis of the works [17, 20] are presented in table 2. These levels may be presented graphically in the form of defined symbols or in numbers. For every worker, a competency level should be determined according to the identified competencies in step 2.

*4. Analysis of the results and determining training needs.*

On the basis of the results, a competency matrix should be developed in a graphic form. The developed competency matrix will allow to identify the areas of a low competency level (a competency gap). Each identified area should be assessed. Trainings are primarily required in the area in which the most competency levels with 0 or 1 values were identified.

### 5.3.2. Development a competency matrix in the analysed enterprise

In the analysed enterprise, a starting point for designing a matrix was to establish the most essential skills, knowledge, workers' attitudes in both the areas of the machines operated and activities realized in autonomous and preventive maintenance. The required competencies were identified in two areas: operated machines and the realized maintenance activities. In the area of the operated machines, four basic types of machines were identified. Among the realized activities, six basic activities were specified: replacement and replenishment media, machine inspection, reaction to basic failures, machine maintenance, fulfilling of the repair and defects cards and vibration measurement. The kind of identified activities results from the specificity of the works realized in the enterprise. Next, competencies for particular workers were identified and their levels were established according to table 2. On the basis of the collected information, a competency matrix was designed – table 3.

In order to assess a competency level of the assessed workers, a number of workers who possess a certain competency level on a given area should be determined quantitatively. Table 4 presents such an analysis for the given enterprise.

The area which primarily needs training is the one with the largest number of competency levels of: first with 0 value, then with 1 value. In the analysed enterprise, these activities are: vibrations measurement, replacement and replenishment media, reactions to basic failures, fulfilling repairs and defects cards, and machine operations of type 1 and 4. A training schedule should be developed for these areas.

*Table 2. Levels of workers' competencies.*

| Level | Symbol | Characteristic |
|---|---|---|
| Level 4 | 4 | A worker may train others. |
| Level 3 | 3 | A worker may independently perform certain tasks. |
| Level 2 | 2 | A worker possesses knowledge and improves his/his skills, but still needs supervision . |
| Level 1 | 1 | A worker is acquiring knowledge and skills. |
| Level 0 | 0 | A worker doesn't possess knowledge or skills to perform certain tasks. |

*Table 3. A competency matrix of workers*

| Competency levels | Machines | | | | Activities | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Machine operation type 1 | Machine operation type 2 | Machine operation type 3 | Machine operation type 4 | Replacement and replenishment media | Machine inspection | Reaction to basic failures | Machine maintenance | Fullfilling the repairs and defects cards | Vibration measurement |
| **Worker 1** | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 1 | 4 | 4 |
| **Worker 2** | 4 | 1 | 3 | 0 | 2 | 3 | 0 | 2 | 3 | 4 |
| **Worker 3** | 1 | 4 | 3 | 0 | 3 | 4 | 0 | 2 | 2 | 0 |
| **Worker 4** | 0 | 2 | 4 | 2 | 4 | 3 | 3 | 3 | 1 | 0 |
| **Worker 5** | 0 | 2 | 0 | 3 | 0 | 3 | 1 | 3 | 0 | 0 |
| **Worker 6** | 3 | 1 | 4 | 4 | 0 | 0 | 3 | 4 | 0 | 4 |

*Table 4. Results of a competency assessment*

| Competency levels | Machines | | | | Activities | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Machine operation type 1 | Machine operation type 2 | Machine operation type 3 | Machine operation type 4 | Replacement and replenishmer media | Machine inspection | Reaction to basic failures | Machine maintenance | Fullfilling the repairs and defects cards | Vibration measurement |
| 4 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 |
| 3 | 1 | 1 | 3 | 2 | 2 | 4 | 2 | 2 | 1 | 0 |
| 2 | 1 | 2 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 0 |
| 1 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 2 | 1 | 0 | 2 | 2 | 0 | 2 | 0 | 2 | 3 |

### 5.3.3. Level II – indicative assessment of the level of competency on the basis of competency matrix developed

A competency matrix analysis can be easily done if there are only a few workers. When the number of them is larger, such as analysis in significantly impeded because of the great number of data. Based on the work [2], it is proposed to introduce a indicative assessment of the maintenance workers' competencies as:

1. The total indicator of a competency assessment for a particular worker ($W_{kc}$).
2. The indicator of workers' competency in a given area (one chosen activity or one type of an operated machine) ($W_{ko}$).

The total indicator of a worker's competency ($W_{kc}$) describes a level of each worker competency for all the realized activities, both in machines operation as well as their supervision. The indicator should be calculated from the formula (1).

$$W_{kc} = \frac{(\sum D_0 \cdot 0) + \sum D_1 \cdot 1 + \sum D_2 \cdot 2 + \sum D_3 \cdot 3 + \sum D_4 \cdot 4}{\sum D_n \cdot 4} \cdot 100\% \quad (1)$$

where:

$W_{kc}$ – is an indicator of one worker's competency,

$D_o$ – an aggregate number of activities for which a worker possesses 0th level competency ($D_o$ parameter was put into brackets because there is no need to write it in the formula, however it should be remembered that it has influence on $D_n$ parameter and at the same time on the $W_{kc}$ indicator result),

$D_1$ – an aggregate number of activities for which a worker possesses 1st level competency,

$D_2$ – an aggregate number of activities for which a worker possesses 2nd level competency,

$D_3$ – an aggregate number of activities for which a worker possesses 3rd level competency,

$D_4$ – an aggregate number of activities for which a worker possesses 4th level competency,

$D_n$ – a number of all specified activities in total.

It was assumed that $W_{kc}$ indicator value must be larger than 60 ($W_{kc}$> 60%). Such a border value was adopted based on the author's experience and the requirements of the analysed enterprise.

Using the matrix (table 3), a number of activities for which a worker possesses the adequate level of competency was determined. For instance: worker 1 doesn't possess competencies on the level 0, possesses one competency on the levels 1 and 2, five competencies on the level 3 and four competencies on the level 4. Using the formula (1), the value of $W_{kc}$ competency indicator for particular workers in the analysed enterprise was determined (Tab. 5).

The analysis of the obtained results shows that only 2 out of 6 workers fulfil competency requirements - $W_{kc}$ > 60%. The remaining workers have to undergo additional trainings. In order to determine the scope of these trainings, a competency analysis in the chosen area should be conducted (one chosen activity or one type of operated machines) ($W_{ko}$).

The indicator of the workers' competency level (a maintenance team) totally in relation to a given activity should be calculated from the formula (2):

$$W_{ko} = \frac{(\sum P_0 \cdot 0) + \sum P_1 \cdot 1 + \sum P_2 \cdot 2 + \sum P_3 \cdot 3 + \sum P_4 \cdot 4}{\sum P_n \cdot 4} \cdot 100\% \quad (2)$$

where:

$W_{ko}$ – a competency indicator of a team within a given activity,

$P_0$ – a number of activities with workers possessing 0th level competency ($P_o$ parameter was put into brackets because there is no need to write it in the formula, however it should be remembered that it has influence on $P_n$ parameter, and at the same time on the $W_{ko}$ indicator result),

$P_1$ – a number of workers with the 1st level competency,

$P_2$ – a number of workers with the 2nd level competency,

$P_3$ – a number of workers with the 3rd level competency

$P_4$ – a number of workers with the 4th level competency,

*Table 5. The values of $W_{kc}$ indicator in the analysed company*

| Worker | Number of activities for which a worker possesses an adequate level of competency | | | | | Competency indicator $W_{kc}$ [%] |
|---|---|---|---|---|---|---|
| | ⊕ 0 | 1 | 2 | 3 | 4 | |
| Worker 1 | 0 | 1 | 1 | 5 | 3 | **75** |
| Worker 2 | 2 | 1 | 2 | 3 | 2 | **55** |
| Worker 3 | 3 | 1 | 2 | 2 | 2 | **47** |
| Worker 4 | 2 | 1 | 2 | 3 | 2 | **62** |
| Worker 5 | 5 | 1 | 1 | 3 | 0 | **32** |
| Worker 6 | 3 | 1 | 0 | 2 | 4 | **57** |

$P_n$ – an aggregate number of workers (a maintenance team) being assessed.

Furthermore, it was assumed that the indicator values are $W_{ko} > 60\%$.

Table 6 presents the established values of the competency indicator $W_{ko}$ for particular activities of the assessed maintenance team in the analysed enterprise.

Analysing the results it can be noticed that 6 out of 10 of the assessed activities take the value under 60%. It means that in these areas a competency gap appears. The lowest assessed area is the maintenance of type 1 machines and fulfilling the repairs and defects cards – 42%, and for these areas, in the first place, a training should be organized. In order to identify training needs for particular workers, the assessment results presented in tables 3, 5 and 6 should be considered. In addition, in order to determine training needs the following assumptions were made:

1. In the first place, workers and the areas for which the value of competency indicators $W_{ko}$ and $W_{kc}$ value is lower than 60% were identified,
2. It was assumed that there should be at least one worker with the competency level 4 and minimum two workers with the competency level 3 in every area,
3. If the assumption 2 is met in a given area, and the competency indicator value is lower than 60%, the workers with the lowest competency level in a given area, are to be trained in the first place.

Table 7 presents a proposal of training needs after taking into consideration the established assumptions.

The presented analysis explicitly determines which worker in which area should be trained. In the first place, training needs for the areas and workers with the lowest competency levels should be realized. Thanks to such a solution, it will be possible to provide highly qualified staff in every maintenance area that is being realized. Workers' competencies will be increased ensuring that tasks performance will fulfil the specified standards and will guarantee the right exploitation of devices and machines.

### 5.3.4. Level III: Assessing the risk of providing a competency level

The identification of a competency gap in an enterprise in many cases is related to the provision of adequate financial resources for their supplementing. In practice, it is very difficult, particularly, for small companies. Thus, what is important is the possibility of the assessment of not providing an adequate competency level of maintenance workers, and, at the same time, of the incorrect realization of a maintenance process. That is why, it is essential to design a risks matrix together with an effective analysis of a risk assessment process in order to optimize resources provision. It is proposed to design such a risk matrix on the basis of $W_{ko}$ indicator values in relation to the consequences (machine availability – *A* and the Mean Time Between Failures – *MTBF*) that may appear at the wrong level of the competencies provision. Table 8 shows a designed risk matrix. The matrix shows at which values of $W_{ko}$ indicators, the risk of not providing the right level of machine availability (*A)* and *MTBF* changes in relation to the realized activities (areas). The matrix identifies 5 risks levels (from very low - VL to very high – VH). It was designed on the basis of the author's experience, the data from the analysed company and with the support of a maintenance expert.

If the values of $W_{ko}$ and *MTBF* as well as *A* indicators are in the middle of each range, there is no problem in estimating the risk. However, if these values are at the borders of the ranges, there is a possibility of a subjective assessment of the risk level. What's more, the analysis results may influence such uncertainty depending on the

*Table 6. The values of $W_{ko}$ indicator in the analysed company*

| Competency levels | Machines | | | | Activities | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Machines operation type 1 | Machines operation type 2 | Machines operation type 3 | Machines operation type 4 | Replacement and replenishment media | Machine inspection | Reaction to basic failures | Machine maintenance | Fulfilling the repairs and defects cards | Vibration measurement |
| Level 4 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 1 | 4 | 4 |
| Level 3 | 4 | 1 | 3 | 0 | 2 | 3 | 0 | 2 | 3 | 4 |
| Level 2 | 1 | 4 | 3 | 0 | 3 | 4 | 0 | 2 | 2 | 0 |
| Level 1 | 0 | 2 | 4 | 2 | 4 | 3 | 3 | 3 | 1 | 0 |
| Level 0 | 0 | 2 | 0 | 3 | 0 | 3 | 1 | 3 | 0 | 0 |
| ***Competency indicator $W_{ko}$ [%]*** | **42** | **52** | **71** | **58** | **50** | **67** | **46** | **67** | **42** | **50** |
| ***Average value* [%]** | **57** | | | | **53** | | | | | |

*Table 7. Proposals of trainings.*

| Worker | Competency indicator $W_{kc}$ [%] | Machines | | | | Activities | | | | | | Average value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Machines operation type 1 | Machines operation type 2 | Machines operation type 3 | Machines operation type 4 | Replacement and replenishment media | Machine inspection | Reaction to basic failures | Machine maintenance | Fulfilling the repairs and defects cards | Vibration measurement | |
| Worker 1 | **75%** | | | | | | | | | | | 55 |
| Worker 2 | **55%** | | + | | + | | | + | | | | |
| Worker 3 | **47%** | + | | | + | | | + | | + | + | |
| Worker 4 | **62%** | | | | | | | | | | | |
| Worker 5 | **32%** | + | | | | + | | | | + | + | |
| Worker 6 | **57%** | | + | | | + | | | | + | | |
| **Competency indicator $W_{ko}$ [%]** | | **42** | **58** | **71** | **58** | **50** | **67** | **46** | **67** | **42** | **50** | |
| ***Average value* [%]** | | **57** | | | | **53** | | | | | | |
| | | **54** | | | | | | | | | | |

*Table 8. The risk assessment matrix*

| | Consequences | Descriptive variable | Consequences | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Linguistic values** | VH | H | M | L | VL |
| | | | **MTBF [h]** | >800 | 600 – 800 | 400– 600 | 200– 400 | <200 |
| | | | **A (%)** | 80 to 100 | 60 to 80 | 40 to 60 | 20 to 40 | < 20 |
| | $W_{ko}$ % | | **Risk level** | 1 | 2 | 3 | 4 | 5 |
| Competency level | >80 | VH | 1 | **VL** | **VL** | **VL** | **VL** | **VL** |
| | >60 | H | 2 | **M-L** | **M-L** | **L** | **L** | **L** |
| | >40 | M | 3 | **M-H** | **M-H** | **M-H** | **M-L** | **M-L** |
| | >20 | L | 4 | **VH** | **VH** | **H** | **H** | **H** |
| | ≤20 | VL | 5 | **VH** | **VH** | **VH** | **VH** | **VH** |
| | | | **Risks: VH= very high; H = high; M-H = medium to high; M- medium; M-L = medium to low; L = low; VL = very low** | | | | | |

available information, knowledge and experience. In these circumstances it is possible to use fuzzy inference based on logic. In this context, the matrix of the risk assessment will be used as the basis for developing the rules for fuzzy inference.

This work presents Mamdani – type fuzzy inference. It is possible to select appropriate membership functions and, with the support of experts, determining the values of these functions within the adopted ranges. The values of $W_{ko}$ and *MTBF* as well as $A$ indicators will constitute the input into the system of fuzzy inference in order to calculate the risk level. The analysed case will present the determination of the values of the risk level which is supported by fuzzy logic for $W_{ko}$ and availability ($A$) indicator. Input and output parameters are expressed in the quantitative, qualitative and linguistic values. Membership functions described by the formula [3] were adopted for modelling. This function, as presented in works [7, 20, 28], was used in order to minimize the discrepancy between the reality and mathematical modelling:

$$\text{Gaussian}(x;c,\sigma) = e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{3}$$

where c is the centre, $\sigma$ describes the width of a membership function. "Gauss2mf" function, which is available in MATLAB (R2012) programme, was used for modelling [15, 16]. The function described by the formula (4) is a combination of two parameters ($c$, $\sigma$) [15]:

$$y = \text{gauss2mf}\{x, [\sigma_1\ c_1\ \sigma_2\ c_2]\} \tag{4}$$

MATLAB (R2012) tool was used for performing the proposed process of fuzzy inference [16]. Fig. 5 presents a fuzzy interference model.

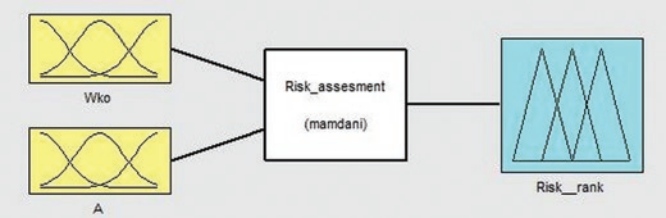


*Fig. 5. Fuzzy logic model*

Fig. 6 presents some rules which were designed based on table 8.

1. If (Wko is VH) and (A is VH) then (Risk__rank is VL) (1)
2. If (Wko is VH) and (A is H) then (Risk__rank is VL) (1)
3. If (Wko is VH) and (A is M) then (Risk__rank is VL) (1)
4. If (Wko is VH) and (A is L) then (Risk__rank is VL) (1)
5. If (Wko is VH) and (A is VL) then (Risk__rank is VL) (1)
6. If (Wko is H) and (A is H) then (Risk__rank is ML) (1)
7. If (Wko is H) and (A is VH) then (Risk__rank is ML) (1)
8. If (Wko is H) and (A is M) then (Risk__rank is L) (1)
9. If (Wko is H) and (A is L) then (Risk__rank is L) (1)
10. If (Wko is H) and (A is VL) then (Risk__rank is L) (1)

*Fig. 6. Inference rules*

Fig. 7, 8, 9 present membership functions for $W_{ko}$, availability ($A$) and a risk level.

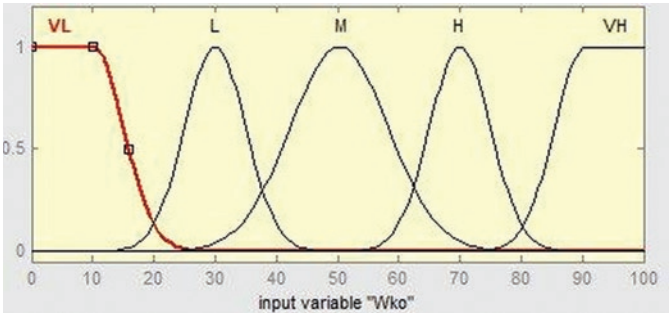


*Fig. 7. GCMF of $W_{ko}$*

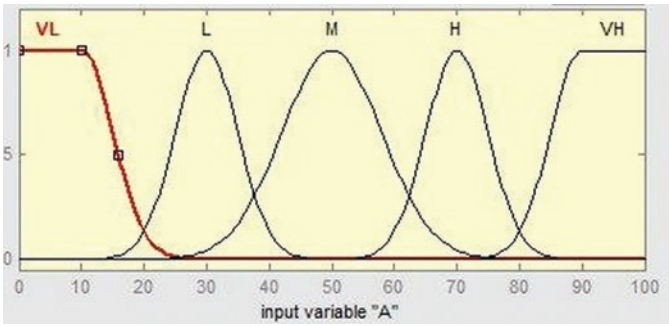


*Fig. 8. GCMF of A*

*Table 9. Gaussian MF parameters for input and output variables*

| Input | VL | L | | M | H | VH |
|---|---|---|---|---|---|---|
| *A, $W_{ko}$* | [5 0 5 10] | [5 30 5 30] | | [8 50 8 50] | [5 70 5 70 | [5 90 5 100] |
| Output | VL | L | M-L | M-H | H | VH |
| Risk rank | [0.2 0 0.2 0.5] | [0.3 1 03 1] | [0.3 2 0.3 2] | [0.3 3 0.3 3] | [0.3 3.75 0.3 3.75] | [0.2 4.5 0.1 5] |

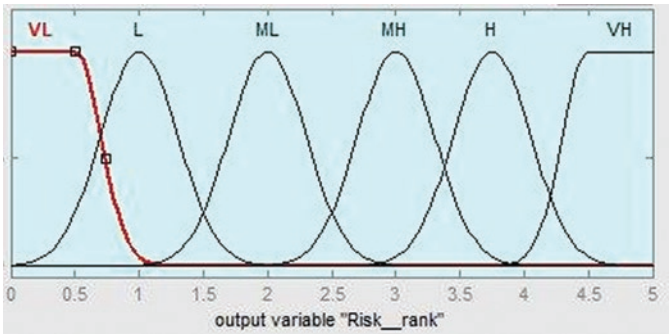


*Fig. 9. GCMF of a risk level*

Table 9 presents the adopted values of Gaussian membership function at input and output.

Figure 10 presents inference rules and the example of determining the risk level of the consequences of not providing an adequate competency level for the realization of supervision activities over machines and devices.

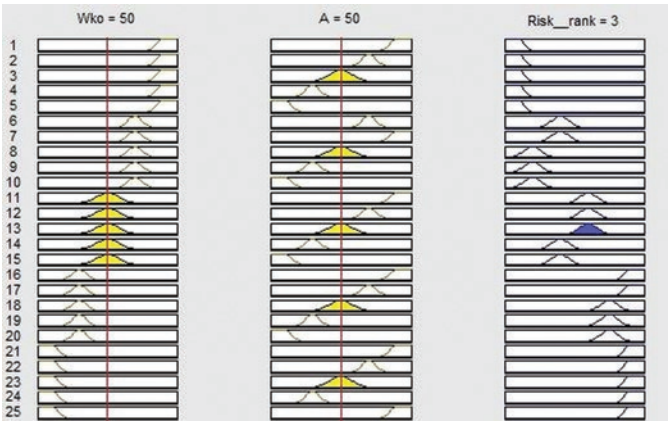


*Fig. 10. Risk level calculation*

The calculation of the risk level was conducted for $W_{ko}$ indicator value $W_{ko} = 50$ and D=50. The risk was assessed at the level = 3. The centroid method was used as a defuzzification method. Rule 8 is the strongest in action. It means that the risk of sustaining machine availability on the level 50, at such a competency level, is described as medium.

This analysis will allow to determine on which level a competency indicator should be maintained in order to minimize the risk of its influence on efficiency and effectiveness of the realized in maintenance.

## 6. Summary and conclusions

Effectiveness of a maintenance process in an enterprise requires competent and aware workers. The study results presented in the first part of the work showed that companies are aware of the need of the maintenance workers' competency assessment. In many companies, these assessments are realized, and on their basis conclusions are drawn and improvement action is undertaken. Many companies, particularly small, do not carry out such actions. That's why, presented the second part of the work, the three-level methodology of workers' competency assessment and the example of its use in the given enterprise may help such companies in the selection

of an adequate competency assessment. The use of an adequately selected method of a competency assessment shall allow to: identify a current level of competencies, but, most of all, to identify the training needs, in order to improve efficiency and effectiveness of the maintenance process realization.

The proposed work has some limitations due to the fact that the method was verified in one company only. That's why, in the further work, this method will be verified in other companies as well. The results of this verification will allow to identify the limitations deriving from companies functioning and to identify additional essential requirements, which the assessment should take into account.

The implementation of this method is time-consuming. It needs collecting certain information, not only related to workers but also machines, e.g. MTBF indicator, what in many companies, particularly small ones, is organisationally difficult. Therefore, further works should try to support the process of the workers' assessment with the use of the data collected in CMMS systems. That would allow to obtain the needed information and, at the same time, to facilitate the process of the workers' assessment.

## References


1. Abele E, Reinhart G. Zukunft der Produktion, München: Hanser, Carl, 2011.
2. Baron – Puda M. Projektowanie strategii rozwoju kompetencji pracowników przedsiębiorstw produkcyjnych. Zarządzanie przedsiębiorstwem 2012; 4: 2-11.
3. Bokrantz J, Skoogh A, Berlin C, Stahre J. Maintenance in digitalised manufacturing: Delphi-based scenarios for 2030. International Journal of Production Economics 2017: 191: 154-169.
4. Dalkilic S. Improving aircraft safety and reliability by aircraft maintenance technician training. Engineering Failure Analysis 2017; 82: 687-694,https://doi.org/10.1016/j.engfailanal.2017.06.008.
5. Furman J. Poprawa skuteczności utrzymania maszyn w przedsiębiorstwie produkcyjnym – studium przypadku. Komputerowe Zintegrowane Zarządzanie, 2016:548-557.
6. Gonczi A, Hager P, Athanasou J. The Development of Competency-Based Assessment Strategies for the Professions National Office of Overseas Skills Recognition, Australia: 1993.
7. Greenstein L. Assessing 21st century skills: A guide to evaluating mastery and authentic learning SAGE: 2012.
8. Hameed A. Using Gaussian membership functions for improving the reliability and robustness of students' evaluation systems. Expert Systems with Applications 2011; 38(6): 7135–7142, https://doi.org/10.1016/j.eswa.2010.12.048.
9. Herterich M, Uebernickel F, Brenner W. The Impact of Cyber-Physical Systems on Industrial Services in Manufacturing. Procedia CIRP 2015; 30: 323-328, https://doi.org/10.1016/j.procir.2015.02.110.
10. Hertlea C, Tischa M, Kläsa H, Metternicha J, Abelea E. Recording Shop Floor Management Competencies – A Guideline for a Systematic Competency Gap Analysis. Procedia CIRP 2016; 57: 625 – 630, https://doi.org/10.1016/j.procir.2016.11.108.
11. Jasiulewicz-Kaczmarek M, Drożyner P. Preventive and Pro-Active Ergonomics Influence on Maintenance Excellence Level, [in.] M.M. Robertson (eds.) Ergonomics and Health Aspects, HCII 2011, LNCS 6779 Springer-Verlag Berlin Heidelberg, ISBN 978-3-642-21715-9 2011; 49-58.
12. Jasiulewicz-Kaczmarek M, Saniuk A, Nowicki T. The maintenance management in the macro-ergonomics context. [in.] Richard H.M. Goossens (eds.) Advances in Social & Occupational Ergonomics Proceedings of the AHFE2016 Conference on Social & Occupational Ergonomics, July 27-31, Walt Disney World®, Florida, USA Series: Advances in Intelligent Systems and Computing 2016; 487:35-46, https://doi.org/10.1007/978-3-319-41688-5.
13. Kaufhold M. Kompetenz und Kompetenzerfassung.VS, Verl Für Sozialwiss, 2006.
14. Loska A. Scenario modeling exploitation decision-making processes in technical network systems. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2017; 19 (2): 268–278, https://doi.org/10.17531/ein.2017.2.15.
15. Mathworks. Fuzzy inference system modelling: Gaussian combination membership function, 2014. available: http://www mathworks se/help/fuzzy.
16. Matlab, MATLAB 7 12 0 (R2011a), Fuzzy logic Toolbox, 1984–2014 The MathWorks, Inc , 2014.
17. Misiurek B. Metodyka standaryzacji autonomicznych działań eksploatacyjnych zorientowana na poprawę efektywności maszyn zautomatyzowanych, Praca doktorska, Uniwersytet Technologiczny we Wrocławiu, 2015.
18. Muller A, Marquez A C, Iung B. On the concept of e-maintenance: Review and current research. Reliability Engineering and System Safety 2008; 93:1165-1187, https://doi.org/10.1016/j.ress.2007.08.006.
19. Müllera R, Vette M, Geenen A. Skill-based dynamic task allocation in Human-Robot-Cooperation with the example of welding application. Procedia Manufacturing 2017: 13 – 21.
20. Paśkiewicz J. Doskonalenie procesu nadzoru maszyn na przykładzie wybranego przedsiębiorstwa, diploma thesis under supervising K. Antosz, Rzeszów, 2016.
21. Pellegrino J, Justiniano M, Raghunathan A. Measurement Science Roadmap for Prognostics and Health Management for Smart Manufacturing Systems, NIST Advanced Manufacturing Series 2017; 191: 154-169.
22. Pittich D. Diagnostik fachlich-methodischer Kompetenzen, Fraunhofer IRB Verl, 2013.
23. Ratnayake RMC. Knowledge based engineering approach for subsea pipeline systems FFR assessment: A fuzzy expert system. The TQM Journal 2016; 28:40–61, https://doi.org/10.1108/TQM-12-2013-0148.
24. Rodriguez D, Patel R, Bright A, Gregory D, Gowing M K. Developing competency models to promote integrated human resource practices. Human Resource Management 2002; 41(3): 309-324, https://doi.org/10.1002/hrm.10043.
25. Roy R , Stark R, Tracht K, Takata S, Mori M. Continuous maintenance and the future - Foundations and technological challenges. CIRP Annals -Manufacturing Technology 2016; 65: 667-688. https://doi.org/10.1016/j.cirp.2016.06.006
26. Schlick C, Bruder R, Luczak H. Arbeitswissenschaft. 3. Auflage Springer-Verlag, 2010, https://doi.org/10.1007/978-3-540-78333-6.
27. Sherwin D J. A review of overall models for maintenance management Journal of Quality in Maintenance Engineering 2000; 1(1): 15-19, https://doi.org/10.1108/13552519510083101.

28. Shingo S. Study of "Toyota" Production system from industrial engineering viewpoint Tokyo: Japan Management Association, 1981.
29. Smith R, Mobley R K. Maintenance Skills Assessment, Industrial Machinery Repair 2003: 26–49, https://doi.org/10.1016/B978-075067621-2/50003-2.
30. Stadnicka D, Arkhipov D, Battaıa O, Ratnayake RMC. Skills management in the optimization of aircraft maintenance processes. IFAC PapersOnLine 2017; 50(1): 6912–6917, https://doi.org/10.1016/j.ifacol.2017.08.1216.
31. Tay K M, Lim C P. On the use of fuzzy inference techniques in assessment models: part II: industrial applications. Fuzzy Optimization and Decision Making 2008; 3:283–302, https://doi.org/10.1007/s10700-008-9037-y.
32. Wirkus M, Drozd R, Bielski R. Production employees competence in apparatus processes. Management Forum 2015; 3(30:63-70.
33. Zio E. Reliability engineering: Old problems and new challenges. Reliability Engineering & System Safety 2009; 94:125-41.

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