ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20240514152419

Preliminary communication
Received: 2024-05-14, Accepted: 2024-06-22

Method to Assess Computerised Systems Supporting Maintenance Services

Michał Pająk*, Bogdan Landowski, Łukasz Muślewski, Dragutin Lisjak

Abstract: There are many CMMS (Computerized Maintenance Management Systems) systems on the market in a wide range of prices and capabilities. An important problem for enterprise decision-makers is the selection of a system supporting maintenance services, appropriate for the specificity of the enterprise. The study presents an analysis of methods for assessing and selecting this type of systems and proposes a subjective-point method for analysing this type of issues. The issues presented in the study are part of the work on the development of materials and tools supporting enterprise decision-makers in the process of analysing existing solutions and selecting IT systems supporting maintenance services. Additionally, survey research was carried out, which enabled the generation of a database of basic values for the features of selected products, evaluation criteria, and in particular the determination of weight values for individual criteria, which contributed to the automatic execution of calculations for the adopted assumptions.

Keywords: CMMS; Computer Aided Systems; Computerised Maintenance Management; Maintenance; Selection Method

1 INTRODUCTION

Computerized Maintenance Management Systems (CMMS) are intended to support maintenance subsystem (maintenance engineering) of all types of enterprises where technical objects are operated. They enable the collection of information on failures of objects and operating processes carried out in the enterprise, along with their detailed descriptions for machines, devices and vehicles, as well as the development of periodic and preventive inspection schedules and their queuing [1]. Formal definition can be found in [2]. According to it a computerized maintenance management system (CMMS) is any software package that maintains a computer database of information about an organization's maintenance operations.

The pursuit of a continuous increase in the efficiency of enterprise operations with the constant increase in requirements regarding product quality and the growing complexity of manufacturing processes, as well as the increase in the number of regulations and formal and legal requirements mean that one of the key elements determining the development of an enterprise is the ability to effectively use IT and telecommunications techniques.

Methods for assessing IT systems supporting maintenance engineering and optimizing the selection of these systems for a specific enterprise can be divided into two main groups: objective methods based on mathematical optimization tasks and subjective methods based on the analysis of selected criteria with assignment appropriate weights of them. However, in industrial practice, in vast majority cases the evaluation methods belonging to the second group mentioned above are used.

The decision-maker selects a quasi-optimal CMMS system from many possible solutions, taking into account, often contradictory, selection criteria. In practice, the decision-maker builds a summary table of all the data "for" and "against" affecting the choice of a given solution and hierarchizes the systems from the used set of assessment criteria point of view.

In order to support the decision-making process of the CMMS systems selection and reduce the degree of its subjectivity, research was carried out, the result of which is the CMMS software evaluation system described in this paper.

The remaining part of the paper is organized as follows: Chapter 2 describes the basic goals and functions of CMMS systems, and Chapter 3 presents an analysis of existing multi-criteria analysis methods. On this basis, an evaluation method is proposed in Chapter 4 and a system for evaluating CMMS programs is defined in Chapter 5. Chapter 6 describes the survey research conducted, presents and analyses its results. The paper is summarized in Chapter 7.

2 GOALS AND BASIC FUNCTIONS OF CMMS SYSTEMS

The increasing degree of automation of production and service processes as well as technical and technological progress with the simultaneous constant increase in requirements regarding the safety of use of technological machines and products, as well as the pursuit of reducing production costs result in an increase in the importance of maintenance subsystems in the structure of the company. This also involves the need to use IT systems supporting maintenance engineering.

It is possible to distinguish general principles, which are widely accepted and must always be taken into account when selecting devices, including computer devices and IT systems. These are functionality, reliability and durability, efficiency, purchase and implementation costs, operating costs, availability of consumables, ease of use, ergonomics and compliance with applicable standards and regulations.

The purchase and implementation of an appropriate CMMS system depends on the requirements formulated for this type of systems by decision-makers, the type of production or services provided, the type of technological devices used (including their complexity and level of automation), the size of the enterprise and organizational structure of the company.

It should be noted that software systems supporting maintenance processes are only a tool and the benefits of their implementation depend not only on their proper selection from the point of view of the specific nature of the enterprise and the goals set formulated for them by decision-makers, but also on their rational use and knowledge as well as the ability to use their capabilities and functions. The correct formulation of the goals and requirements for CMMS systems is a necessary condition for their proper selection and obtaining the expected effects from their implementation.

The general objectives that can be achieved by the implementation and rational use of software which supports maintenance subsystems are the following: reducing costs while ensuring the required level of readiness and reliability of the technical objects in operation, reducing machine downtime and increasing the efficiency of service processes. These objectives can be expressed by the following list of particulars goals [3, 4]:

- creating comprehensive documentation regarding the machines, tools and other technical objects used and ensuring easy and quick access to this data by authorized persons,
- standardization of the terminology used,
- supporting planning processes for handling and purchasing consumables and spare parts,
- recording and processing of data regarding operational events,
- reducing machine downtime,
- quick analysis of data regarding failures of technical objects,
- automatic generation of developed report templates for selected time intervals (working times, service times, downtime, etc.)
- identification of costs related to service processes, including the possibility of recording and analysing costs by type,
- optimization of the management of consumables and spare parts (including automation of the processes of making orders),
- control, analysis and optimization of material resources,
- identification of machine nodes particularly susceptible to damage,
- identification of repetitive failures,
- increasing the efficiency and quality of service processes thanks to increased employee involvement achieved by identifying their activities.

The basic functions of CMMS systems are:

- recording and processing data regarding technical objects in use (process lines, machines included in them, standalone devices) and means of operation,
- mapping the enterprise structure (decomposition of the organizational and technical structure to the adopted level of detail) and its visualization,
- recording and processing data regarding service processes (to the extent determined by the decision-makers),
- supporting and planning the service processes
- recording the scope of service activities and their automatic generation for a given service,
- automating the generation of orders for the execution of service processes, defining scope of activities, employees performing the service, list of necessary tools and consumables, forwarding orders and documentation for specific positions in the company
- management of authorizations of employees providing services,
- settlement of completed works,
- automatic generation of required reports and periodic and current reports,
- recording and settlement of costs including types and centres,
- monitoring (alerting) about scheduled service dates.

The scope of functions offered by the CMMS systems available on the market are significantly expanded in relation to the basic functions listed above. The diversity of functions of this type of systems, on the one hand, enables the appropriate selection of the system to suit the specificity and needs of the enterprise, but on the other hand, it makes it difficult (due to the lack of unification) to analyse these systems and their proper selection.

3 ANALYSIS OF EXISTING SELECTION METHODS

In fact, the choice of a CMMS system can be reduced to formulating a system of n inequalities with m variables, where n is the number of criteria and m is the number of arguments of these criteria. In the case of one-dimensional criteria, there is a relationship $m \leq n$. Since in a multi-criteria evaluation system there are in most cases contradictory or partially mutually exclusive criteria, the formulated system of inequalities is often contradictory (rarely undefined). This means that there is often a situation when none of the considered variants of the solution (CMMS systems) satisfies the system of inequalities, or many of the assessed systems meet such a system. It is therefore necessary to use such an evaluation method that in each case (contradictory, definite and undefined system of inequalities) it is possible to rank the assessed solutions and clearly select the best one. It is proposed to accomplished this task through the use of multi-objective analysis method [5].

The main goal of multi-objective analysis is to rank the assessed variants in a specific order and, if possible, to determine the overall quality of individual variants in the form of assigning appropriate grades or scores [6]. There are many methods of multi-criteria analysis, but they are all based on a common scheme. The first phase of the analysis is to determine the criteria that make up the multi-criteria evaluation system. Given that, each criterion can and usually concerns a completely different field and there are usually both quantitative and qualitative criteria. An evaluation method is introduced that allows assigning a grade to each variant according to each criterion. In addition, a system of weights for the criteria is introduced, allowing for differentiating the importance of individual assessments. It is also possible to introduce weights ranking the impact of the assessments of individual decision-makers on the final assessment, if there are many of them. The final stage is the process of calculating the total score of a given variant using a specific algorithm. This process includes the evaluation of the variant according to individual criteria, the weight of individual criteria and the weight of decision-makers, if they are introduced. Because of the final process, the variants are ranked in terms of their total rating value. It should be noted that the possibility of simple interpretation of the obtained total assessment value is very helpful in the practical application of the analysis.

Analysing scientific databases as Web of Science and Scopus in the field of assessment methods it can be noticed that commonly used multi-criteria evaluation methods are linear and relational methods. These are the main assessment techniques groups. Therefore in the paper the comparison will be limited to them. The first group consists of hierarchical linear methods. Representative method of the first group is the point method. It occupies a special place in quality assessment because it combines all separately assessed features into one number that comprehensively expresses the overall quality of the examined object [7]. It is based on the hierarchy of system elements and their distance from the achievable maximum value. The assessment is based on the adoption of a specific scale. The hierarchy is characterized by an ascending or descending order indicating the degree of fulfilment of the global criterion, including all sub-criteria. The result of the point method is a ranking of the tested variants from the point of view of the degree to which the requirements are met. The significant advantages of this method are the resistance to high differences in observations, the ability to compare quantitative and qualitative features simultaneously, simple and understandable structure, the relative ease of interpretation, short implementation time and low testing costs.

The precision of the obtained results depends on the proper definition of individual quality levels and this is the first condition to obtain meaningful results. The second condition is the training of the assessment team, allowing clear understanding of the definition of individual features of the object. Definitions cannot contain concepts that are emotional or too general [8].

The second group are relational methods. The example of relational methods is the AHP (Analytic Hierarchy Process) method. There are two preparatory stages in it. First stage consists in a hierarchically superior determination of the relative dominance of criteria. It is obtained from pairwise comparison of them. The second one is the calculation of the relative dominance of individual solution in terms of subsequent criteria. The final step is the determination of synthetic scores organizing the assed solutions and the analysis and interpretation of the method results [9, 10].

While in point methods the assessment is given taking into account one's own feelings as to the fulfilment degree of a given criterion by the object separately from other objects, in relational methods the differences in fulfilment degree by individual objects are mainly taken into account. In point methods, relations between criteria can be externally imposed in the form of a preference vector. In contrast, in relational methods they are calculated as a preference vector from the dominance matrix. There are many similarities between the analysed methods, but the interpretation of the results of the AHP method is much more difficult. None of them takes into account the correlations between the criteria [8]. To summarize the differences, it should be emphasized that in the point method, points are awarded on the basis of predetermined criteria, so it is an absolute assessment, while in relational methods, elements are compared and ranked relative to each other. Therefore, it is a relative assessment.

4 ASSUMPTIONS OF CMMS ASSESSMENT METHOD

Based on the analysis performed, it is proposed to use the point method to evaluate IT systems supporting maintenance engineering.

The key element of the assessment method are the assessment criteria formulated on the basis of the objectives that should be achieved through the implementation and rational use of electronic systems supporting maintenance subsystems. Analysing the objectives identified above, it was stated that the evaluation criteria are both quantitative (reduction of machine downtime expressed in hours) and qualitative (standardization of the terminology used expressed on a subjective evaluation scale). Therefore, the proposed assessment method must meet the assumptions of a multi-criteria assessment combining both types of criteria into a coherent assessment system. It was decided to use a fuzzy extension of the SMART multi-objective assessment method.

It should be noticed that the use of elements of fuzzy logic allows for modelling ambiguously specified assessment criteria and taking into account the subjective nature of the assessment according to qualitative criteria [11].

In the SMART method [6], the criterion domain is determined based on the upper and lower range of variability of the criterion argument. It is assumed that the range of variability is divided into six intervals, the sizes of which increase with the distance from the optimum according to a geometric series with a quotient equal to two. Depending on the type of criterion, they are described by different functions. For the criterion where the most desirable value is the smallest value or the largest possible value, the function takes the form Eq. (1):

$$v = \log_2\left(\frac{P_v - P_{\min}}{P_{\max} - P_{\min}} \cdot 64\right), \tag{1}$$

For the criterion where the most desired value is the largest value, the function takes the form Eq. (2):

$$v = \log_2\left(\frac{P_{\max} - P_v}{P_{\max} - P_{\min}} \cdot 64\right), \tag{2}$$

For the function values corresponding to the arguments defined by Eq. (3) for criterion (1) and Eq. (4) for criterion (2), a scale from 4 to 10 is introduced according to Eq. (5).

$$P_v = P_{\min} + (P_{\max} - P_{\min}) \cdot \frac{2^v}{64}, \; v = 0, 1, ..., 6 \tag{3}$$

$$P_v = P_{\max} + (P_{\max} - P_{\min}) \cdot \frac{2^v}{64}, \; v = 0, 1, ..., 6 \tag{4}$$

$$g = 4 + v, \tag{5}$$

where: v - the value of the criterion function, $P_{\max}$ – the upper range of variability of the criterion argument, $P_{\min}$ – the lower range of variability of the criterion argument, P_v - the argument of the criterion function, g – the degree of the criterion fulfilment.

For criterion (1), with the desired value as high as possible, a scale from 4 to 10 is introduced according to the formula (6):

$$g = 10 - v. \tag{6}$$

A normalized weight c is determined for each criterion. The total rating of variant s is calculated according to formula (7)

$$s = \sum_{i=1}^{k} c_i \cdot g_i. \tag{7}$$

The value of the final grade ranges from 4 to 10. This allows for verbal interpretation of the value (Tab. 1).

Table 1 Interpretation of the variant's total rating value

Total rating values	Interpretation
10	Ideal
9	Very good
8	Good
7	Poor
6	Very poor
5	Bad
4	Very bad

The lack of precision in determining the degree of fulfilment of individual criteria and the possibility of distinguishing individual variants from the considered criteria point of view should be modelled by describing each criterion with a fuzzy set with a membership function consisting of straight lines. The shape of the broken membership function curves depends on the type of criterion determined using the theory of multi-objective analysis.

For the criterion for which the smallest value is most desirable (MINSIMP), a membership function with the shape shown in the Fig. 1, calculated based on Eqs. (1), (3) and (5). The criterion in which the biggest value is most desirable (MAXSIMP) is modelled as a membership function calculated using Eqs. (2), (4) and (5) (Fig. 2). While, in the case of the criterion for which the biggest possible value is the most desirable (MAXINV), the membership function presented in the Fig. 3 is used. It is calculated using Eqs. (1), (3) and (6).

The presented functions are scaled to the appropriate size of the fuzzy set domain by dividing the set fuzzy set support into 64 equal parts. The criterion domain is assumed equal to the support of the fuzzy set. The function values for the support elements range from 4 to 10. In order to describe the criteria by normal fuzzy sets, these values are divided by 10.

Developing an evaluation system according to the described above multi-objective analysis method involves defining a set of evaluation criteria, determining for each of them the type of criterion and the range of argument variability. Additionally, for each of them the weights determining the importance of individual criteria should be assign.

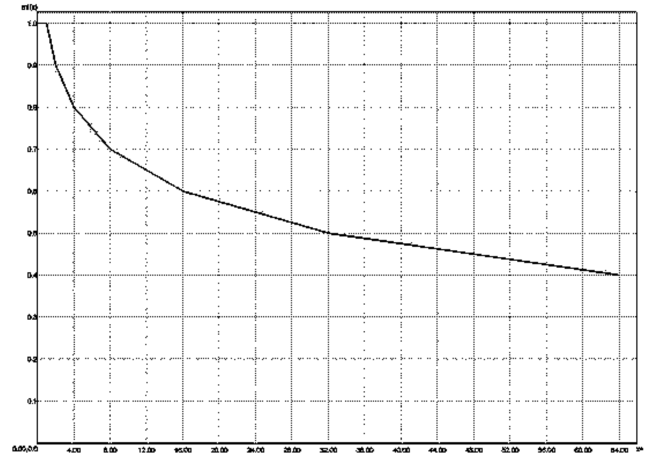

Figure 1 Membership function of the MINSIMP criterion

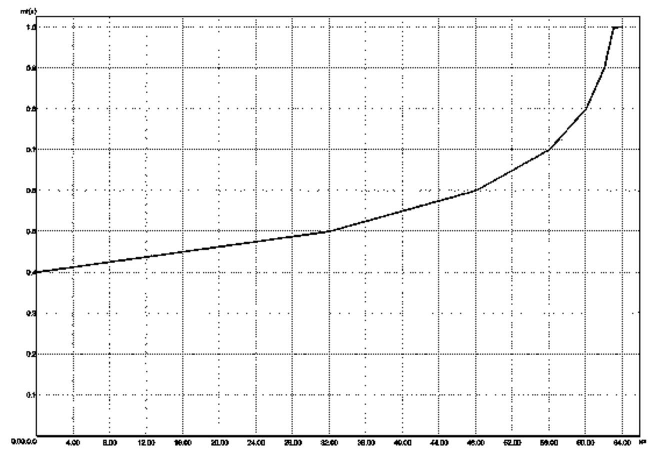

Figure 2 Membership function of the MAXSIMP criterion

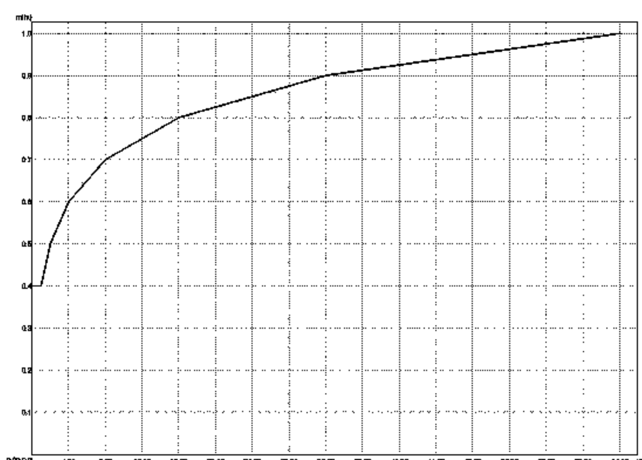

Figure 3 Membership function of the MAXINV criterion

For quantitative criteria, the degree of fulfilment of the criterion is clearly defined, while for qualitative criteria it is a subjective assessment dependent on an expert. In such cases, the use of fuzzy inference was proposed.

For the argument, uniform partitioning was introduced using seven fuzzy sets, the first of which is of the L type, the last of the Γ type, and all intermediate ones of the Λ type [12]. The sets denote the linguistic terms very small (VL), small (L), medium small (ML), medium (M), medium high (MH), high (H) and very high (VH) (Fig. 4).

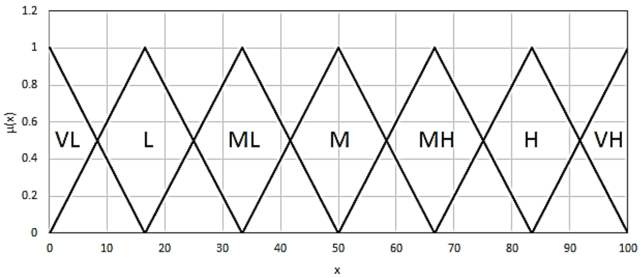

Figure 4 Partitioning of the argument range

Experts describe the argument value using the introduced scale. Then, similarly to the fuzzy controller [13], the degree of activation of individual fuzzy sets is determined based on the percentage of expert responses consistent with a given fuzzy set. On this basis, a numerical value is determined by using the height operator (8) [14] . Based on the determined value, the degree of fulfilment of the criterion is found.

$$x_{\mathrm{H}} = \frac{\sum_{i=1}^{k} h(FS_i) \cdot x(h(FS_i))}{\sum_{i=1}^{k} h(FS_i)}, \tag{8}$$

where: x_{H} – the sharp value of the criterion argument, k – the amount of the criteria, FS_i – i^{th} fuzzy set, $h(FS_i)$ – the height of i^{th} fuzzy set, $x(h(FS_i))$ – the position of height of i^{th} fuzzy set.

For the used selection criteria system, the team of experts will assess the degree to which individual criteria are met by the analysed CMMS systems. Additionally, each expert will determine the weight of individual criteria on a scale from 1 to 10. The evaluators (experts) may be specialists in the implementation and operation of this type of systems and managers of maintenance departments in enterprises of the analysed industries.

5 EVALUATION SYSTEM OF THE CMMS SOFTWARE AND PRODUCT EVALUATION SURVEY

Computer systems supporting maintenance engineering facilitate rational and effective management of enterprise resources. Existing solutions in most cases provide the basic functions required for this category of software. However, their degree of complexity, ease of implementation and use, range of additional functions offered, susceptibility to user intervention and adaptation to their specific needs make it very difficult and sometimes impossible to directly compare the offered solutions. This makes the process of selecting the best solution suited to the specificity of the company and its needs more difficult.

Producers and distributors of this type of software, for obvious reasons, do not indicate possible problems and costs related to the implementation and use of the offered systems, only enumerating their advantages, which most often include better use of company resources, which is supposed to enable: reduction of production costs, reduction of stocks and reducing the number of damages to machines and devices used in processes carried out therein.

In order to be able to compare and evaluate software packages to support maintenance engineering, a uniform evaluation system was developed. It was formulated as a result of literature research [15-18], analysis of offers from global [19] and local [20-22] CMMS system manufacturers, and industrial research conducted in selected SME transport companies. The assessment system were formulated based on functions and features of CMMS systems mentioned earlier in the paper. The resulting evaluating system consists of 37 criteria. For each of them, the type of criterion (MINSIMP, MAXSIMP, MAXINV), the type of argument (numerical value - NV, linguistic value - LV) and the range of argument variability were determined (Tab. 2). On this basis, a survey research card was developed in which experts in the field of the problem determine the weights of individual criteria as well as the values of arguments for each of the assessed systems.

Table 2 List of criteria of the formulated evaluation system

No	Criterion	Criterion type	Argument type	Argument range
1	Possibility to modify the form of data and reports presentation	MAXINV	LV	VL-VH
2	Data protection against unauthorized access	MAXSIMP	NV	0-7
3	Implementation time	MINSIMP	NV (days)	30-700
4	Availability of technical support	MAXSIMP	NV (%)	50-100
5	Functionality	MAXINV	LV	VL-VH
6	Comfort of work	MAXINV	LV	VL-VH
7	Annual system operating costs	MINSIMP	NV (KEUR)	0-15
8	Implementation costs	MINSIMP	NV (KEUR)	2-40
9	Purchase costs	MINSIMP	NV (KEUR)	0-400
10	Ease of analysis of operational events	MAXINV	LV	VL-VH
11	Guaranteed system availability	MAXSIMP	NV (%)	80-100
12	Possibility of adaptation to individual needs	MAXINV	LV	VL-VH
13	Possibility of configuration and modification by users	MAXINV	LV	VL-VH
14	Impact on increasing the efficiency of the service system	MAXINV	LV	VL-VH
15	Possibility to reduce stocks	MAXINV	LV	VL-VH
16	Possibility to reduce machine downtime	MAXINV	LV	VL-VH
17	Influence on the optimization of the exploitation strategy	MAXINV	LV	VL-VH
18	Possibility to predict the durability and reliability of machines	MAXINV	LV	VL-VH

Table 3 List of criteria of the formulated evaluation system (continuation)

No	Criterion	Criterion type	Argument type	Argument range
19	Possibility of localization of the system	MAXSIMP	LV	VL-VH
20	Possibility of expanding the system	MAXINV	LV	VL-VH
21	Possibility of cooperation with other systems	MAXINV	LV	VL-VH
22	Reliable operation	MAXSIMP	NV (%)	80-100
23	Resistance of data to damage of IT devices	MAXSIMP	NV	0-7
24	Optimization of the use of technical infrastructure	MAXSIMP	LV	VL-VH
25	Optimization of the use of human resources	MAXSIMP	LV	VL-VH
26	Position of the system manufacturer on the market	MAXSIMP	NV	0-7
27	Complication of use	MINSIMP	LV	VL-VH
28	Complexity of the implementation process	MINSIMP	LV	VL-VH
29	The intensity of system development by the manufacturer	MAXINV	LV	VL-VH
30	Completeness of documentation regarding operational events	MAXSIMP	NV	0-7
31	The degree of usefulness of the functions offered by the system	MAXSIMP	NV (%)	50-100
32	Speed of operation	MAXSIMP	LV	VL-VH
33	Versatility	MAXINV	LV	VL-VH
34	Support for the introduction of ISO performance quality standards	MAXINV	LV	VL-VH
35	Supporting of service processes planning	MAXSIMP	LV	VL-VH
36	Required qualifications of system users	MINSIMP	NV	0-7
37	Compliance to applicable standards and regulations	MAXINV	LV	VL-VH

In the evaluation system, in addition to the criteria formulated for numerical and linguistic values, there are also criteria whose arguments take values from the defined lists. The meaning of these values of the lists for particular criteria is described in the Tab. 3.

Table 4 The meaning of list values for particular criteria

	Criterion				
	2	23	26	30	36
0	Lack	Lack	Single installation	Lack	Lack
1	OS security	Local media backup	Local market participant	Event log	Primary education
2	User / password security	Disk array systems	A niche position on a national market	Log of events divided into groups	Primary with training

Table 5 The meaning of list values for particular criteria (continuation)

	Criterion				
	2	23	26	30	36
3	User / password security with user profiles	Local server backup	A well-known national market participant	Report	Second. education
4	2FA software security	Distributed server backup	Dominant position on a national market	Report divided into events groups	Second. education with training
5	2FA software security with user profiles	Local data mirroring	A niche position on an international market	Report divided into events groups and basic descript.	Higher
6	Hardware-based 2FA security	Remote data mirroring	A well-known international market participant	Report divided into events groups and extended descript.	Higher education with training
7	Hardware 2FA security with user profiles	Cloud solution	A dominant position on an international market	Report of events with full descript.	Expert level

6 SELECTED RESULTS OF ASSESSING CMMS SYSTEMS

In order to verify the applicability of the developed evaluation system, a survey was conducted. The research was carried out by surveying respondents. A set of 23 employees of maintenance departments of transport SME was randomly selected. All respondents had higher technical education. The group of respondents included both the employees supervising maintenance services and the employees directly performing maintenance tasks. A set of criteria for assessing CMMS systems was adopted as a survey. Respondents were to evaluate, on a scale from 1 to 10, the importance of individual criteria (the higher the rating value, the more important the criterion).

In Tab. 4 the results of the conducted surveys regarding the assessment of the significance of the criteria for assessing CMMS can be found. Additionally, the assessment of an exemplary CMMS system is also presented.

A set of 37 evaluation criteria was analysed. The high importance ratings for the analysed criteria are noteworthy. Only 3 out of 37 analysed criteria received an importance rating below 5.

Table 6 Assessment results (scale from 0 to 10) of the importance of the criteria and the grades of the exemplary CMMS system

Criterion no.	Mean weight	Standard deviation	Variation coefficient	CMMS
1	9,130	0,869	0,095	0,712
2	6,565	1,950	0,297	0,52857
3	7,217	1,808	0,251	0,55672
4	8,957	0,825	0,092	0,64
5	6,087	1,649	0,271	0,94
6	8,957	0,928	0,104	0,9334
7	9,348	0,714	0,076	0,59333
8	7,348	1,799	0,245	0,63158
9	4,130	1,180	0,286	0,58

Table 7 Assessment results (scale from 0 to 10) of the importance of the criteria and the grades of the exemplary CMMS system (continuation)

Criterion no.	Mean weight	Standard deviation	Variation coefficient	CMMS
10	9,261	0,689	0,074	0,9574
11	6,217	2,255	0,363	0,74
12	8,130	1,424	0,175	0,7072
13	5,565	1,502	0,270	0,7328
14	9,391	0,656	0,070	0,9026
15	5,261	2,281	0,434	0,9028
16	9,304	0,703	0,076	0,904
17	9,696	0,470	0,049	0,924
18	7,348	1,584	0,216	0,9214
19	6,870	2,117	0,308	0,5
20	6,174	2,037	0,330	0,9334
21	6,522	3,189	0,489	0,884
22	9,783	0,422	0,043	0,84
23	9,739	0,449	0,046	0,52857
24	8,783	0,951	0,108	0,4868
25	9,304	0,703	0,076	0,4974
26	3,043	1,637	0,538	0,48571
27	9,565	0,590	0,062	0,4532
28	5,913	1,505	0,255	0,448
29	8,217	0,850	0,103	0,9668
30	6,696	1,820	0,272	0,68571
31	9,435	0,662	0,070	0,58
32	9,217	0,850	0,092	0,5668
33	3,870	1,486	0,384	0,7328
34	8,696	0,926	0,107	0,9014
35	9,826	0,388	0,039	0,4948
36	8,739	1,137	0,130	0,48571
37	9,913	0,288	0,029	0,9334

Analysing the obtained results, it can be concluded that in the set of 37 analysed criteria, three subsets of criteria can be distinguished, based on the value of the coefficient of variation of the obtained assessments of their importance.

The first subset of 15 criteria is characterized by a low coefficient of variation ($v < 0.1$). This means that respondents were very consistent in their assessments of the importance of the analysed criteria. At the same time, this subset of criteria includes criteria that received the highest importance rating (above 9). There is a correlation between the average value of the obtained weights and the dispersion of individual respondents' ratings around the average value.

The second subset, consisting of 15 criteria, is characterized by a coefficient of variation value ranging from 0.1 to 0.3 ($0.1 < v < 0.3$). It seems that such a dispersion of the obtained ratings may result from the respondents' different preferences, goals and expectations for CMMS systems.

The third subset of 7 criteria is characterized by a relatively high value of the variation coefficient ($v > 0.3$). This means a large discrepancy among respondents as to their assessments of the importance of the analysed criteria. At the same time, this subset of criteria includes criteria that received a relatively low importance rating.

In order to obtain an assessment of the exemplary CMMS system, the obtained criteria weights were normalized by dividing each of the weights by their sum. Thanks to this, the weights sums to 1. Then, 10 multiplied the calculated ratings of the considered CMMS system in order to obtain a rating consistent with the SMART method. Finally, using Eq. (7), the total score of the system was calculated. The score was equal to 7.1, which can be interpreted in accordance with the table (Tab. 1) as poor quality of the analysed solution.

The obtained results confirm the validity of the adopted assumptions of the method for assessing CMMS systems, both in terms of the need to use the possibility of individual criteria weights selection and the suitability of the developed set of criteria for the assessment of this type of systems. The analysis of the obtained results may be useful in the process of selecting from among existing CMMS systems the solutions that best meets the expectations of enterprise decision-makers (hierarchization of criteria). It can be also useful for producers and enterprises dealing with the distribution and implementation of this type of software packages.

7 SUMMARY

An important problem for enterprise decision-makers is the selection of a system supporting maintenance services, appropriate for the specificity of the enterprise. The considerations presented in this work constitute the assumptions of the method for assessing IT systems supporting maintenance services. The elements of the method are a defined set of criteria, the method of determining the assessment in the case of criteria formulated for numerical and linguistic arguments, and the procedure for calculating the weights of the criteria, the degree of fulfilment of individual criteria, as well as the final assessment of the analysed CMMS system.

The study presents an analysis of methods for assessing and selecting this type of systems and proposes a subjective-point method to use. The issues presented in the study are part of the method of supporting enterprise decision-makers in the process of analysing existing solutions and selecting IT systems supporting maintenance services.

The conducted surveys proved the accuracy of the selection of evaluation criteria and the usefulness of the proposed method for assessing CMMS systems. There are many CMMS systems on the market in a wide range of prices and capabilities. Information about available packages of this type, compiled in a uniform and coherent form, will enable enterprise decision-makers to conduct a preliminary analysis of existing solutions and facilitate the process of selecting software tailored to the needs of a given enterprise.

The main limitations of the research are the comparison of only two most popular assessment methods. Therefore, it is planned to extend the analysis in the future. It is also planned to use the developed assessment method to create a computer system supporting the CMMS system selection process. Such a system will support the formulation of criteria, determining their types, the range of variability of arguments, and the shape and location of fuzzy sets used to partition the range. It will also automatically perform the calculations necessary to obtain the final score of the assessed solution.

8 REFERENCES

[1] Ogbo, A. I., Eneh, N. C. J., Mbah, C. N. & Isijola, D. O. (2018). Effects of comp manufacturing companies in Enugu state, Nigeria. *Sci Technol, 4*, 38-51.

[2] Cato, W. W. & Mobley, R. K. (2002). *Computer-Managed Maintenance Systems* (Second Edition). Chapter 2 - Definition of a CMMS. Woburn: Butterworth-Heinemann, 13-55. https://doi.org/10.1016/B978-075067473-7/50002-4

[3] Aliyu, A., Baglee, D. & Dixon, D. (2023). Computerised maintenance management system (CMMS) role in small and medium enterprise (SME). *Proc Int Conf Cond Monit Asset Manag 2023*, 1-7. https://doi.org/10.1784/cm2023.2f5

[4] Lopes, I., Senra, P., Vilarinho, S., Sá, V., Teixeira, C., Lopes, J., et al. (2016). Requirements specification of a computerized maintenance management system–a case study. *Procedia Cirp, 52*, 268-273. https://doi.org/10.1016/j.procir.2016.07.047

[5] Mansouri, S. A., Lee, H. & Aluko, O. (2015). Multi-objective decision support to enhance environmental sustainability in maritime shipping: A review and future directions. *Transp Res Part E Logist Transp Rev, 78*, 3-18. https://doi.org/10.1016/j.tre.2015.01.012

[6] Muślewski, Ł., Pająk, M., Migawa, K. & Landowski, B. (2022). An expert system for optimizing the operation of a technical system. *J Qual Maint Eng, 28*,131-153. https://doi.org/10.1108/JQME-05-2020-0033

[7] Silverman, D. (2020). *Qualitative Research*. London: SAGE Publications Ltd.

[8] Denzin, N. K. & Lincoln, Y. S. (2017). *The SAGE Handbook of Qualitative Research*. SAGE Publications, Inc.

[9] Bhatt, N., Guru, S., Thanki, S. & Sood, G. (2021). Analysing the factors affecting the selection of ERP package: A fuzzy AHP approach. *Inf Syst E-Bus Manag, 19*, 641-682. https://doi.org/10.1007/s10257-021-00521-8

[10] Kahraman, C., Onar, S. C., Öztayşi, B., Şeker, Ş. & Karaşan, A. (2020). Integration of fuzzy AHP with other fuzzy multicriteria methods: a state of the art survey. *J Mult Log Soft Comput, 35*.

[11] Ali, A., Ullah, K. & Hussain, A. (2023). An approach to multi-attribute decision-making based on intuitionistic fuzzy soft information and Aczel-Alsina operational laws. *J Decis Anal Intell Comput, 3*, 80-89. https://doi.org/10.31181/jdaic10006062023a

[12] Pedrycz, W. (2021). *An Introduction to Computing with Fuzzy Sets Analysis, Design, and Applications*. Cham: Springer Ltd. https://doi.org/10.1007/978-3-030-52800-3

[13] Mohammadzadeh, A., Sabzalian, M. H., Zhang, C., Castillo, O., Sakthivel, R. & El-Sousy, F. F. M. (2023). *Modern Adaptive Fuzzy Control Systems*. vol. 421. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-17393-6

[14] Veerraju, N. & Prasannam, V. L. (2021). Solving Fuzzy Linear Programming Problem Using Defuzzification Method. *Commun Math Appl, 12*, 335.

[15] Abu Bakar, Z. & Kamaruzzaman, S. N. (2023). Facility Manager's Acceptance of CMMS in Malaysia: an Exploratory Study Using PLS-SEM Approach. *J Surv Constr Prop, 14*, 83-93. https://doi.org/10.22452/jscp.vol14no1.7

[16] Mahabir R, Punb KF. Improving CMMS-integrated Equipment Reliability in Compliance with the IS0 41001: 2018 Standard: A Case Study n.d.

[17] Meira, D., Lopes, I. & Pires, C. (2020). Selection of computerized maintenance management systems to meet organizations' needs using AHP. *Procedia Manuf, 51*, 1573-1580. https://doi.org/10.1016/j.promfg.2020.10.219

[18] Hamodi, H. & Aljumaili, M. (2017). Data Quality of Maintenance Data: A Case Study in MAXIMO CMMS. *Maint. Perform. Meas. Manag. (MPMM 2016)*. Novemb. 28, Luleå, Sweden, Luleå tekniska universitet, 105-110.

[19] IBM Maximo Application Suite n.d. https://www.ibm.com/products/maximo (Accessed on March 2, 2024)

[20] System CMMS dla działów utrzymania ruchu n.d. https://qrmaint.pl/system-cmms/ (Accessed on March 2, 2024)

[21] System CMMS do utrzymania ruchu n.d. https://www.astor.com.pl/oferta/oprogramowanie-przemyslowe/systemy-cmms.html (Accessed on March 2, 2024)

[22] CMMS Maszyna SMART - centrum pomocy i dokumentacji n.d. https://www.neuron.com.pl/cmms-help/r1.html (Accessed on March 2, 2024)

Authors' contacts:

Michał Pająk, PhD D.Sc. Eng. Associate Professor
(Corresponding author)
Faculty of Mechanical Engineering, Casimir Pulaski Radom University,
ul. Stasieckiego 54, 26-600 Radom, Poland
+48483617149, m.pajak@uthrad.pl

Bogdan Landowski, PhD Eng. Assistant Professor
Faculty of Mechanical Engineering, University of Technology and Life Sciences,
al. Prof. S. Kaliskiego 7, 85-789 Bydgoszcz, Poland
+48523408211, lbogdan@pbs.edu.pl

Łukasz Muślewski, PhD D.Sc. Eng. Associate Professor
Faculty of Mechanical Engineering, University of Technology and Life Sciences,
al. Prof. S. Kaliskiego 7, 85-789 Bydgoszcz, Poland
+48523408298, lukasz.muslewski@pbs.edu.pl

Dragutin Lisjak, PhD Eng. Full Professor
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 5, 10000 Zagreb, Croatia
+ 385 6168 377, dragutin.lisjak@fsb.hr