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Creation of the servicing information to support the maintenance of a technical object with the use of three-value logic diagnostic information

K e y w o r d s

Servicing system, expert systems, knowledge base, diagnostic information.

S ł o w a k l u c z o w e

System obsługiwania, systemy ekspertowe, baza wiedzy, informacja diagnostyczna.

S u m m a r y

The paper presents a method to construct the structure of a system for servicing of reparable technical objects. In the method proposed, diagnostic information from an artificial neural network and expert knowledge were used. The manner of realisation of the servicing model of an object was presented. An important stage in the proposed method of the development of the structure of a system for servicing of an object is the way in which the internal structure of a complex object is converted together with its functional elements to the form of the object's servicing structure. The article also covers an analytical basis for the determination of servicing information (servicing expert knowledge) which organises the system for the servicing of a technical object. Analytical bases were presented of the process of restoration of the functional properties of the object of servicing.

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1. Introduction

The state of the technical object changes during the exploitation from the nominal state for which this object was designed. As a result, the usability features decrease in time, which usually decreases the functionality and/or the quality of the object. Among the set of indexes which characterise the process of the usage presented in literature [4, 11], the two which reflect object's usability features best are the usage quality function ($F_C(t)$) and the usage quality ratio (F_C).

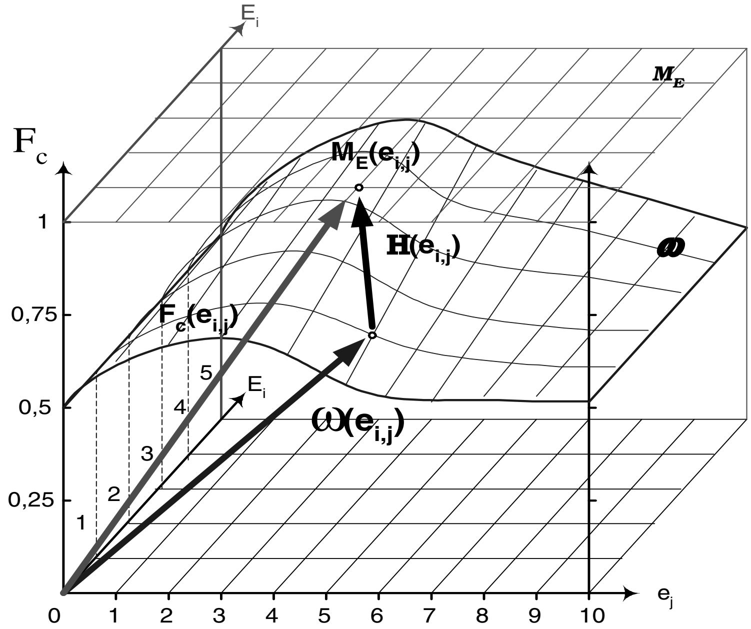
Usage function of the object ($F_C(t)$) describes quality of object's performances considering its purpose and characteristic.

The state of object is determined by the subset of its physical properties [1, 2, 11], which are significant concerning the tasks of the object.

The technical state of the object in a given time of the use determines the possibilities of the realisation of its required functions. It is determined by a subset of its physical properties [1, 2, 3, 7, 9, 11, 12, 13], which describe a given object. For practical reasons, to the states of the object in the diagnosing process, numerical values are assigned, which depend on the logic of the classification of the states applied. For divalent logic, these are states from set {1, 0}, where: "1" is the operational state, and "0" is the non-operational state. For the trivalent assessment of the classification of states [1, 2, 3, 4, 7], to the states of the object, states marked with the values from set {2, 1, 0}, were assigned, where: "2" – the state of full operation; "1" – the state of incomplete usability; "0" – the state of non-operation (defect).

The problem of the description of a technical object: "an incomplete usability state," which is presented among other things in the author's papers [3, 4, 5, 8]: technical diagnostics presents the basis and organisation of diagnostic inference in technical objects as the final element of diagnosing. The effect of diagnostic inferring is the determined (recognised) states of the object's functional elements, on the basis of which the object's resultant stage is determined. Diagnosis of a technical object can also be performed in divalent logic {1, 0} or trivalent logic {2, 1, 0}. The basis for the diagnosis of technical objects is constituted by possible changes of the values of output diagnostic signals (mainly in the analogue form, but also in other forms) from the object's functional elements. Divalent logic constitutes the basis for the application of the trivalent logic of the evaluation of the object's states. Changes of the values of diagnostic signals are only in the range of their permissible and boundary changes. The range of these changes for a given object is constant regardless of the type of the valence used for the determination of the object's states. Additionally, for trivalent logic, the range of changes was divided-determined: state {1}, state of incomplete usability.

The quality of the use of an object can be measured with two quantities [1, 2, 7, 9, 11, 13]: the use function of the object $F_C(t)$ and F_C index of the use function of the object (Fig. 1). The values of function $F_C(t)$ are determined by the divergence between the actual state of the object in the space of the use features (ω), and the state of the usability in the nominal space of usability features (M_E) (Fig. 1). The nominal space of usability features (M_E) is determined by elementary nominal vectors of the object's usability function $F_C(e_{i,j})$.



where: ω – the surface of actual usability features of the object; M_E – the surface of the nominal usability features of the object; $F_c(e_{i,j})$ – the value of use function; $\omega(e_{i,j})$ – vector of actual diagnostic signal; $H(e_{i,j})$ – vector of differential metric of diagnostic signal.

Fig. 1. Distribution of changes of object's states during operating time (example)
Rys. 1. Mapa przestrzenna zmiany stanów obiektu w czasie użytkowania (przykład)

The elementary vectors of the object's usability function $F_C(e_{i,j})$ can have various forms (measurable and other ones), and can have different dimensions. Therefore, initiation disproportion that is too large must be smoothed away between the values of these vectors of the object's usable function $F_C(e_{i,j})$ in particular dimensions. One of reliable methods of the transformation of input data (signals), and which is at the same time an effective method, is the normalisation of data in such a manner so that the values should be in the range (0, 1) after the conversion. A normalisation of the metric of any vector of the object's usability function $F_C(e_{i,j})$ consists in a redefinition of k^{th} components of vector $[F_C(e_{i,j})]$ by making calculations in compliance with the following dependence:

$$F_c\left(e_{i,j}\right)=\frac{F_c\left(e_{i,j}\right)_k}{\sqrt{\sum_{k=1}^{K}\left(F_c\left(e_{i,j}\right)\right)_k^2}} \tag{1}$$

where: k – subset of physical properties which determine elementary use functions of j^{th} element in i^{th} unit of the object

Realisation of the object's prevention is a transformation of the information described with diagnostic plane $\{\omega(e_{i,j})\}$ to the level of the servicing information represented with plane $\{H(e_{i,j})\}$ [4, 5, 8]. A reproduction of the qualitative property of usability function F_C of the object in the servicing process on the example of $F_C(e_{i,j})$ is presented in (Fig. 1). It is evident from an analysis of the diagram of the refurbishing of the object present in (Fig. 1) that the vector of qualitative usability function F_C described with quantity $\{\omega(e_{i,j})\}$ during operation is subject to a deviation from nominal state $M_E(e_{i,j})$ by vector $H(e_{i,j})$.

The methods for the creation of a servicing knowledge base were verified using the example of a radar system.

2. The maintenance system for servicing of a radar system "Straight Flush Radar Vehicle."

In order to design the servicing system for an analogue class technical object, in this case it was an air-defence radar device [13], it was needed to determine the internal structure of serviced object and the set of preventive activities for the non-operational elements. The radar system-Straight Flush Radar Vehicle is a part of a surface–to–air–missiles system (SA-6 "GAINFUL"). The purpose of the radar system is to fight air targets (aircrafts, helicopters, rockets, drone vehicles), as well as ground and water targets in the range of missiles. The radar system "Straight Flush Radar Vehicle" presented in Fig. 2 detects (determines the azimuth, distance and height) and controls the air fight. The antiaircraft set is adapted to work regardless of the time of the year and the day, in temperatures from -40°C to +50°C, with a relative humidity of 90 per cent and the wind speed up to 20 m/s.

The radar system-Straight Flush Radar Vehicle is characterised by a high resistance to climactic and natural factors. (SA-6 GAINFUL) system can be operated fully automatically as regards detection, identification, tracking, and raking of targets. The set is adapted to cooperation and coupling with four sources of external information. The radar can rake at the same time 1 target with 1 or 2 rockets fired within a span of 5 [sec] from one or two launchers.

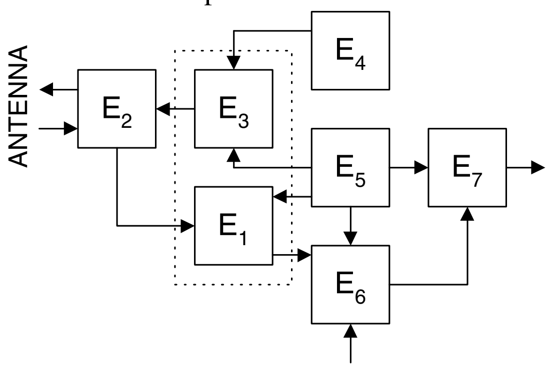
The set considering the specificity of its function of the use (combating of air object) belongs to the group of technical equipment which is characterised by a high index of operational readiness. This class of technical object requires a specific approach as regards the maintenance of their fitness for use states. An optimal preventative strategy for this class of objects is an organisation of the operation of the object according to the state. This means that the technical object used is diagnosed on a continuous basis (state testing).

Fig. 2. The picture of an air-defence radar device of (SA-6) system
Rys. 2. Widok zestawu stacji radiolokacyjnej wykrywania i naprowadzania systemu (SA-6)

The diagnostic system recognises the states of the object and updates the user of the object about a given state. If an incomplete usability state {1} is identified in the object, then the regeneration of the object should begin. Therefore, the basis of the operation of an object in such a system is constituted by a reliable and effective diagnostic system.

The method presented in the present paper concerning the control of the exploitation of a technical object on the basis of its state was verified on the example of a reparable technical object, which is a radar system-Straight Flush Radar Vehicle. A functional and diagnostic analysis of the object was carried out for this purpose. A functional model was prepared and described of the object: a missile homing station of an antiaircraft missile set, which was presented in Fig 3. As a result of the described manner of the division of the object's internal structure, the object was subject to a three-level partition of its structure. As a consequence of this division of the internal structure (Fig. 3), seven functional assemblies were distinguished (E_1, E_2,…, E_7), and up to five basic elements – modules [1, 4, 5, 6] were distinguished in each one of them. As a result of the analysis carried out, a functional and diagnostic diagram was developed, on the basis of which a set of operational elements and a set of output (diagnostic) signals were established.

The method presented of the determination of diagnostic information (state evaluation) [1, 2, 3, 6, 7, 13] in the object examined can be realised with the aid of a module method, particularly when the object examined is a complex object. Then we examine the technical state of the elements-modules in the object on the lowest level of the analysed structure of the object, going "step by step." Diagnosis should begin with the low level of the structure, and should finish on the highest level of this structure, i.e. the object itself. For this purpose, the functional element was subject to an analysis on the second level of the diagnostic structure of the object, which is the functional assembly. For further determination of the diagnostic control (operational) information, assembly E_2: transmitter was chosen as an example.



Where: E_1 – steering (synchronisation) unit, - E_2 – transmitter unit (channel I or channel II), E_3 – receiving unit, E_4 – permanent echo suppression unit, E_5 – display indicator unit, E_6 – precise display indicator unit, E_7 – electric power supply unit of the station.

Fig. 3. The functional scheme of air-defence radar device
Rys. 3. Schemat funkcjonalny zestawu stacji radiolokacyjnej wykrywania i naprowadzania

For the needs of the diagnosing process, a measuring track was designed for the diagnostic system. A properly designed measuring system [5] for the diagnostic system enables one to obtain a reliable measuring knowledge base for the diagnostic system $\{X(e_{i,j})$. The object's measuring information created in this manner constitutes the input information in the diagnosing system with a neural network [4, 5, 8, 10, 14, 15]. The results of measurements for chosen elements of the object are presented Fig. 4.

For the needs of the method presented, an effective diagnostic system [4, 5, 8] was built whose task is to recognise (classify) the object's states in trivalent logics {2, 1, 0}. The diagnostic system used in the tests was constructed on the basis of the measuring information obtained and DIAG diagnosing software. DIAG software is a specialist computer diagnostic programme developed for the needs of the method presented. The diagnostic information obtained during diagnosing in the form of the knowledge base $\{W(\varepsilon(e_{i,j}))\}$ constitutes the input information in the process of obtaining of the expert knowledge base which assists the maintenance of the technical object tested.

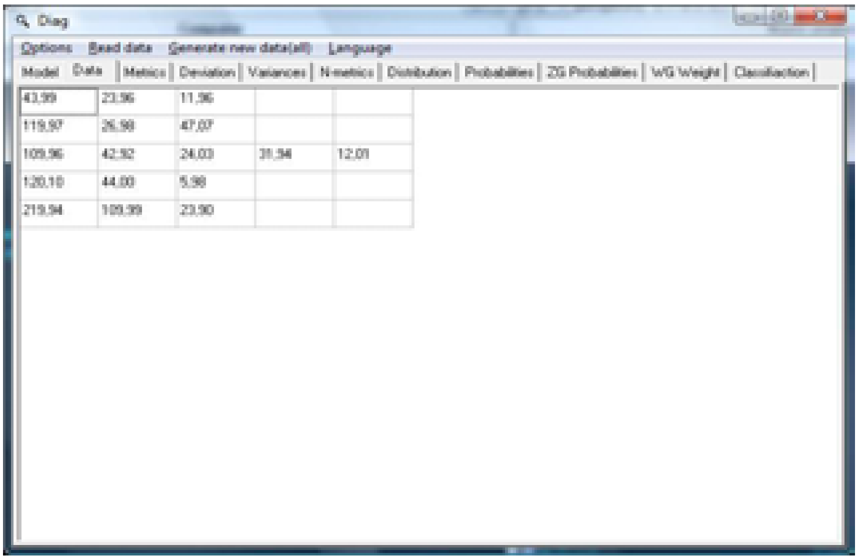


Fig. 4. Matrix of measures of diagnostic signals from the assembly E_2
Rys. 4. Ekran sygnałów diagnostycznych zespołu E_2

The final results obtained of diagnostic programme DIAG [8] were presented in the form of a table of states of the object (Table 1 and Fig. 5).

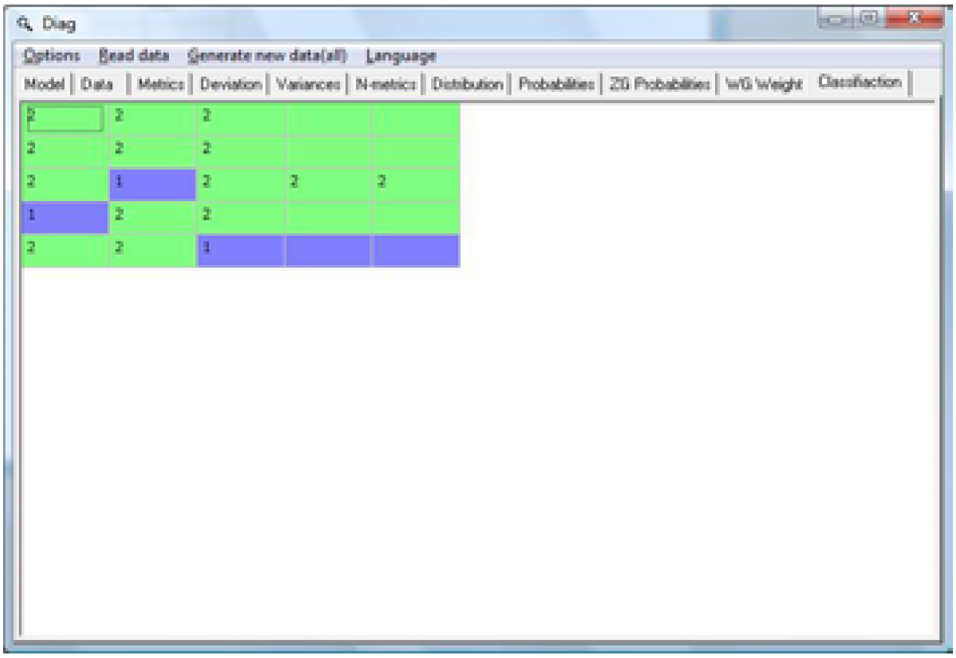


Fig. 5. The result form of DIAG programme “Table of object’s states” of assembly E_2
Rys. 5. Postać wynikowa programu DIAG „Tablica stanów obiektu” dla zespołu E_2

Table 1. Value of states of assembly E_2
Tabela 1. Tabela stanu zespołu E_2

State of the assembly E_2	State of module	Vector of states $\varepsilon(e_j)$				
		e_1	e_2	e_3	e_4	e_5
0	2	2	2	2	∅	∅
	2	2	2	2	∅	∅
	1	2	1	2	2	2
	1	1	2	2	∅	∅
	1	2	2	1	∅	∅

where: Ø – lack of basic element: symbol which completes the size of the Table; {0,1,2} – states of the element

On the basis of the examination of the object's state, tables of states were determined for assembly E_2, and a comparison was made of the states [3, 7] with the model state, which is presented in Tables 2 and 3.

Table 2. Results of comparison of states of assembly E_2
Tabela 2. Wyniki porównania stanów zespołu E_2

Servicing levels	Servicing structure of assembly E_2					
1	⊗	⊗	⊗	⊗	⊗	⊗
	⊗	⊗	⊗	⊗	⊗	⊗
	⊗	1	⊗	⊗	⊗	⊗
	1	⊗	⊗	⊗	⊗	⊗
	⊗	⊗	1	⊗	⊗	⊗

where: ⊗ – lack of basic element: symbol which completes the size of the Table

Table 3. Set of servicing information of assembly E_2
Tabela 3. Zbiór informacji obsługowej zespołu E_2

Servicing levels of assembly	Servicing structure of assembly E_2				
	e_1	e_2	e_3	e_4	e_5
1	⊗	⊗	⊗	⊗	⊗
2	⊗	⊗	⊗	⊗	⊗
3	⊗	$e_{3,2}$	⊗	⊗	⊗
4	$e_{4,1}$	⊗	⊗	⊗	⊗
5	⊗	⊗	$e_{5,3}$	⊗	⊗

On the further state of the listing (development) of the set of the object's operational information, a classification (grouping) of elements [6, 7] was conducted in order to distinguished classes (groups) of operational elements. With the use of the manner of classification of operational elements as presented in the article, the object's functional elements were grouped into operational classes. The results obtained are presented in Table 4.

Table 4. Classes of operational elements of assembly E_2
Tabela 4. Klasy elementów obsługowych zespołu E_2

Class of element	Subassembly of the assembly E_2				
	e_1	e_2	e_3	e_4	e_5
I – electronic	$e_{4,1}$	-	-	-	-
II – mechatronic	-	$e_{3,2}$	-	-	-
III – electric	-	-	$e_{5,3}$	-	-

The set of preventative activities is shown in Table 5. It describes all servicing and maintaining activities, which will be assign to particular elements of servicing structure of the object using relations 13 and relation 14 in [7].

Table 5. The set of preventive activities
Tabela 5. Zbiór czynności obsługowych

The set of preventive activities to renovate of the servicing object	
Replacement with new element	Code of activity
repair	10
Regulation	9
Tuning	8
Regeneration	7
Renovation	6
Conservation	5
Lubrication	4
Cleaning	3
Control checking	2
Replacement with new element	1

The set of diagnostic information (Table 4 and Table 5) was determined based upon above relations (1, 2, 0) and the known table of object states [3, 7]. The results obtained are presented in Table 6.

Table 6. Set of servicing structure of assembly E_2
Tabela 6. Struktura czynności obsługowych w zespole E_2

Servicing levels	Servicing structure of assembly E_2				
	e_1	e_2	e_3	e_4	e_5
1	$\varnothing$	$\varnothing$	$\varnothing$	$\varnothing$	$\varnothing$
2	$\varnothing$	$\varnothing$	$\varnothing$	$\varnothing$	$\varnothing$
3	$\varnothing$	$\{a_1\}e_{3,2}$	$\varnothing$	$\varnothing$	$\varnothing$
4	$\{a_2\}e_{4,1}$	$\varnothing$	$\varnothing$	$\varnothing$	$\varnothing$
5	$\varnothing$	$\varnothing$	$\{a_3\}e_{5,3}$	$\varnothing$	$\varnothing$

Based on information from Table 5 and Table 6, the model of the servicing system for particular object was settled. This model is represented by the set of structural elements and the set of preventive activities in matrix form (see Table 5) [3, 7]. The results obtained are presented in Table 7.

Table 7. Structure of system servicing of assembly E_2
Tabela 7. Struktura systemu obsługiwania dla zespołu E_2

Structure of system of object sevicing	
Element of servicing structure of the object	Elements of preventive activities structure
$e_{3,2}$	{1,2,6,9}
$e_{4,1}$	{1,2,7,9}
$e_{5,3}$	{1,3,6,9}

The set of operational rules $\{R_r(e_{i,j})\}$ constitutes an important subset of the set of operational information, whose diagram was presented in [7]. The set of operational rules was compiled according to the algorithm presented in the article. For this purpose, the previously obtained results in the form of stage sets of operational information were used, which were put in Tables 5, 6 and 7. The results obtained are presented in Table 8 and in Fig. 6.

Table 8. The set of operational rules for assembly E_2
Tabela 8. Zbiór reguł obsługowych dla zespołu E_2

Element no. in E_2 assembly	Rules of operation
$e_{1,1}$	R_1: If $\varepsilon(e_{1,1})$ is $\{\otimes\}$ then $M(e_{1,1}) = M_E(e_{1,1})$
$e_{1,2}$	R_2: If $\varepsilon(e_{1,2})$ is $\{\otimes\}$ then $M(e_{1,2}) = M_E(e_{1,2})$
$e_{1,3}$	R_3: If $\varepsilon(e_{2,1})$ is $\{\otimes\}$ then $M(e_{1,3}) = M_E(e_{1,3})$
$e_{2,1}$	R_4: If $\varepsilon(e_{2,2})$ is $\{\otimes\}$ then $M(e_{2,1}) = M_E(e_{2,1})$
$e_{2,2}$	R_5: If $\varepsilon(e_{2,2})$ is $\{\otimes\}$ then $M(e_{2,2}) = M_E(e_{2,2})$
$e_{2,3}$	R_6: If $\varepsilon(e_{2,3})$ is $\{\otimes\}$ then $M(e_{2,3}) = M_E(e_{2,3})$
$e_{3,1}$	R_7: If $\varepsilon(e_{3,1})$ is $\{\otimes\}$ then $M(e_{3,1}) = M_E(e_{3,1})$
$e_{3,2}$	R_8: If $\varepsilon(e_{3,2})$ is $\{1\}$ then $M(e_{3,2}) \rightarrow \{1,2,6,9,\} = M_E(e_{3,2})$
$e_{3,3}$	R_9: If $\varepsilon(e_{3,3})$ is $\{\otimes\}$ then $M(e_{3,3}) = M_E(e_{3,3})$
$e_{3,4}$	R_{10}: If $\varepsilon(e_{3,4})$ is $\{1\}$ then $M(e_{3,4}) = M_E(e_{3,4})$
$e_{3,5}$	R_{11}: If $\varepsilon(e_{3,5})$ is $\{\otimes\}$ then $M(e_{3,5}) = M_E(e_{3,5})$
$e_{4,1}$	R_{12}: If $\varepsilon(e_{4,1})$ is $\{1\}$ then $M(e_{4,1}) \rightarrow \{1,2,7,9\} = M_E(e_{4,1})$
$e_{4,2}$	R_{13}: If $\varepsilon(e_{4,2})$ is $\{\otimes\}$ then $M(e_{4,2}) = M_E(e_{4,2})$
$e_{4,3}$	R_{14}: If $\varepsilon(e_{4,3})$ is $\{\otimes\}$ then $M(e_{4,3}) = M(e_{4,3})$
$e_{5,1}$	R_{15}: If $\varepsilon(e_{5,1})$ is $\{\otimes\}$ then $M(e_{5,1}) = M(e_{5,1})$
$e_{5,2}$	R_{16}: If $\varepsilon(e_{5,2})$ is $\{\otimes\}$ then $M(e_{5,2}) = M_E(e_{5,2})$
$e_{5,3}$	R_{17}: If $\varepsilon(e_{5,3})$ is $\{1\}$ then $M(e_{5,3}) \rightarrow \{1,3,6,9\} = M_E(e_{5,3})$

The effect of the method presented in the article is the determined set of service information, which was presented in the form of $\{M_E(e_{i,j})\}$. This specialist knowledge base (a set of maintenance information) constitutes the basis for the designing of a reliable system of the maintenance (prevention) of a technical object. The designing of a maintenance system consists in the determination of the structure of the maintenance system (Fig. 6), which is composed of the following: the object's maintenance elements, the prevention activities (depending of the state) selected by an expert, including the maintenance means for a given element $\{A(e_{i,j})\}$, and maintenance rules $\{R_r(e_{i,j})\}$.

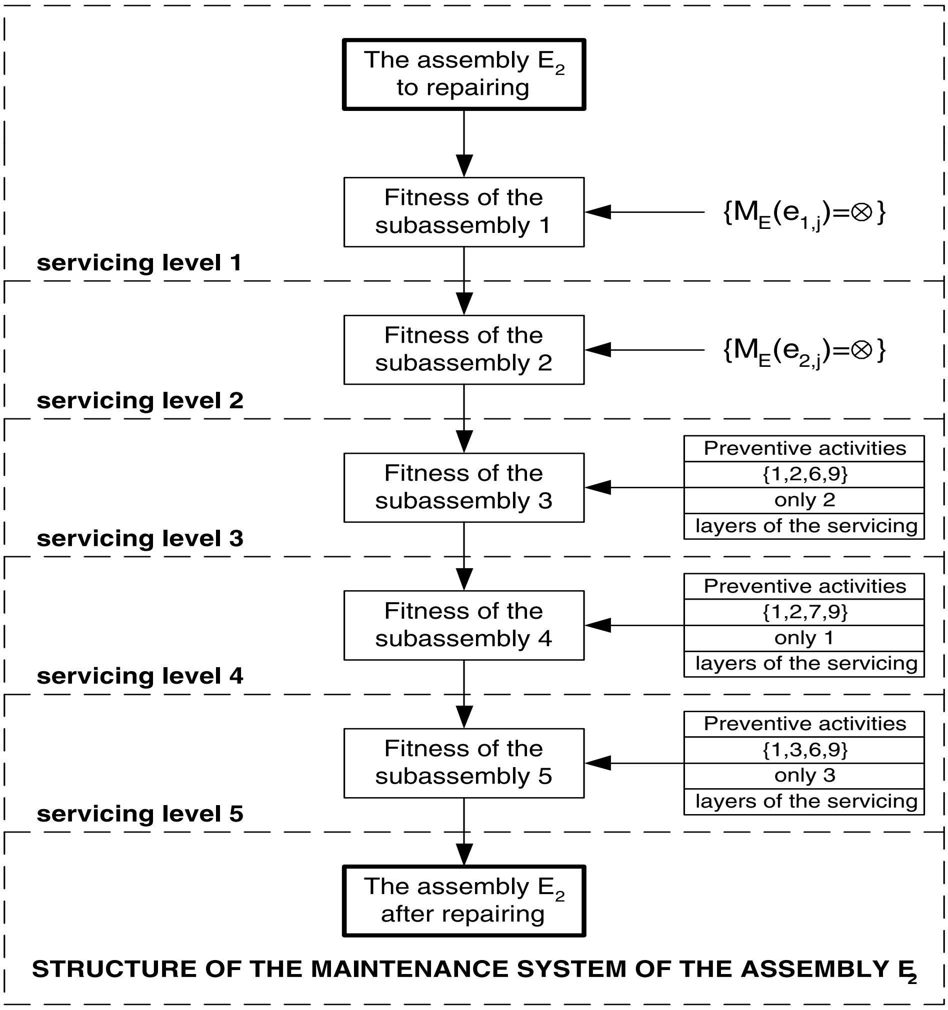


Fig. 6. The scheme of structure of the maintenance system of an assembly E_2
Rys. 6. Schemat struktury obsługowej zespołu E_2

The final form of the maintenance knowledge base was presented in the form of the information included in (Table 8) and Fig. 6. This table includes a set of maintenance rules for assembly E_2. Each rule included in this table determines explicitly which element of a given assembly of the object must be subject to regeneration, and what range of prevention activities (from the set of the activities) is to be performed on it. The execution of the determined set of maintenance rules will result in the regeneration of the whole element, assembly and the whole object. The technical object, once the maintenance has been performed, is subject to a control check-up (testing) of the state, and in the case of a negative result of the control, the object is once again referred to prevention.

The issues presented in the article of the creation (building) of a set of operating information concerns various fields of knowledge, including technical diagnostics, the theory of operation, information technology, expert systems, fuzzy sets, artificial neural networks, etc. Each of these fields is well and broadly worked out in the literature. It is the author's opinion that one can claim with full responsibility that even the basic problem, that is the use of diagnostic information obtained in the diagnosing process of a technical object in the designing and organisation of the operation process, is being constantly developed in various aspects (directions).

At present, the direction of the applications of neural networks, among others in the diagnostics of technical objects, is being intensively developed. However, new solutions and possibilities are constantly being sought; hence, the author's papers and studies are presented concerning a practical application of a trivalent evaluation (classification) of the object's states [4–8].

However, there is no full description in the literature of methods to develop ways and algorithms for the processing of diagnostic information obtained by diagnostic systems: an artificial neural network etc. to the form of an expert knowledge base of a maintenance system, presented in a computer programming language. A new problem, which in the author's opinion requires a solution, is the use of information developed in the trivalent evaluation of information states by the artificial neural network of information (knowledge) for the development of the method to control the prevention of technical objects, referred to in the literature as operation according to the object's state.

3. Conclusions

This paper presents of the method for the creation of an expert knowledge base. An important element of an expert knowledge base is information on the set of the elements of the object's maintenance structure, on the set of preventive activities to renovate the servicing object, on the set of preventive activities to renovate the servicing of technical objects with the required short shutdown time (aeroplanes, radiolocation systems, etc.). The basis of the method proposed is the use of diagnostic information developed by a diagnostic system. The diagnostic information is developed in a diagnostic system of the recognition of the states of a reparable technical object with the use of an artificial neural network. The accepted method of diagnosis by a neural network consists in comparing the image of vectors of diagnostic signals with the images of their models. For this purpose, the technical object examined was subject to a diagnostic study. An important stage of the work is a functional and diagnostic analysis of the object. For this reason, the paper presents and describes the method of the division of the object's internal structure. As a result of this division, a set of basic elements and a set of diagnostic signals were determined.

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Tworzenie informacji obsługowej wspomagającej obsługiwanie obiektu technicznego wykorzystując trójwartościową informację diagnostyczną

S t r e s z c z e n i e

W pracy zaprezentowano metodę konstruowania struktury systemu obsługiwania naprawialnych obiektów technicznych. W proponowanej metodzie wykorzystano informację diagnostyczną ze sztucznej sieci neuronowej oraz wiedzę ekspertową. Zaprezentowano sposób realizacji opracowania obsługowego obiektu. Istotnym etapem w proponowanej metodzie zestawiania struktury systemu obsługiwania obiektu jest sposób przekształcania struktury wewnętrznej złożonego obiektu z jego elementami funkcjonalnymi do postaci struktury obsługowej obiektu. W artykule zawarto również analityczne podstawy wyznaczania informacji obsługowej (obsługowej wiedzy ekspertowej), organizującej system obsługiwania technicznego obiektu. Przedstawiono podstawy analityczne procesu odnawiania własności użytkowych obiektu obsługi.