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Classification of the elements of the object's maintenance structure of a repairable technical object

K e y w o r d s

Technical operation, control systems, technical diagnostics, neural networks, knowledge bases.

S ł o w a k l u c z o w e

Obsługiwanie techniczne, systemy sterowania, diagnostyka techniczna, sieci neuronowe, bazy wiedzy.

S u m m a r y

This paper presents the method for the creation of an export knowledge base. Such a base can be widely use for supporting the process of complex technical object servicing. The first step for is servicing analysis of the object. During this analysis, it is necessary to perform the grouping and classification of the functional elements of the object. It is realised using the functional scheme of the object, which is also presented. Further, diagnostic information is combined with specialised knowledge of experts and becomes transformed into the set of servicing information. The participation of experts in the process of the preparation of an expert knowledge base is significant. The purpose here is to capture information that will be the basis for the design of a servicing system dedicated to the particular technical object. The methods proposed were verified with an appropriate example, where the set of specialised diagnostic information of the object was determined.

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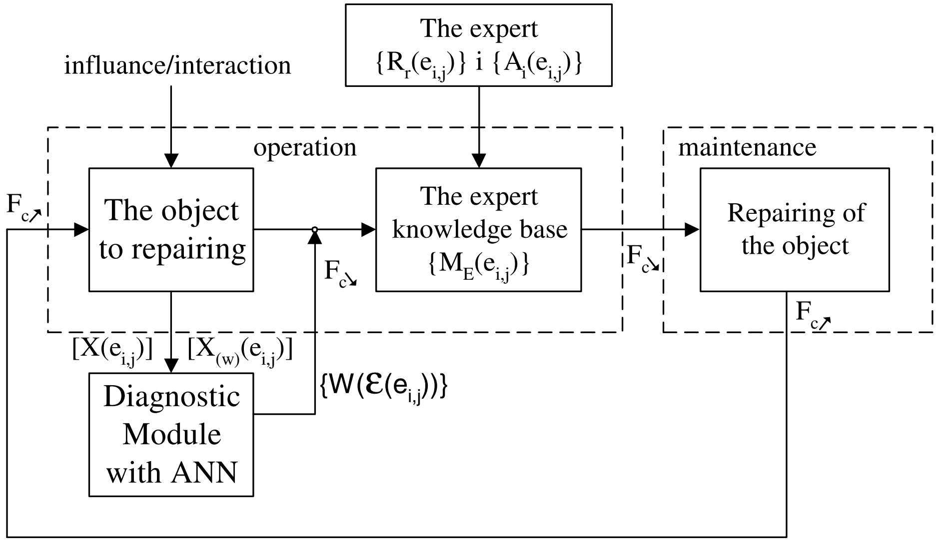
1. Introduction

Repairable technical objects for which a short time of shutdown is required (radar systems, aeroplanes etc.) are frequently equipped with specialist adjustment systems which reconstruct their functional functions to the nominal level. An adjustment system of the object's functionality functions (Fig. 1) is a sophisticated system of the regeneration of the object, which includes subsystems of diagnostics and maintenance [1, 3, 9, 14].

The purpose of the diagnostic system is current and constant recognition (monitoring) of the state of the object [2, 4, 5, 7, 8]. The maintenance subsystem regenerates an object in the states of shutdown through the reconstruction of its functional properties to the nominal level. An adjustment system presented in this manner (Fig. 1) can perform its function, if such a diagnostic system has been developed that will recognise the object's states in the values of trivalent logics {2, 1, 0}. A diagram of the above mentioned process of the control of the operation process by the system of adjustment of the object's functionality function is presented in Fig. 1.

A functional and diagnostic analysis constitutes the basis for the designing of every maintenance system of any technical object. The result is information obtained about the object, including data related to usability, diagnostics, functional properties, special maintenance, etc.



where: $X(e_{i,j})$ – diagnostic signal in j^{th} element of i^{th} set; $X_{(w)}(e_{i,j})$ – model signal for $X(e_{i,j})$ signal; F_C – function of the use of the object

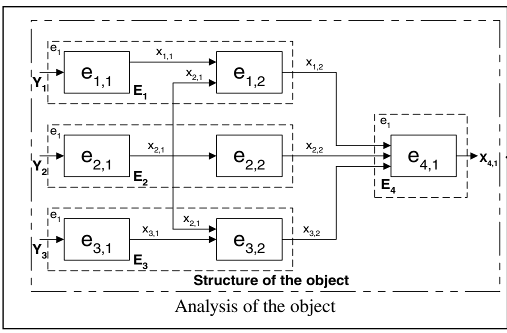
Fig. 1. Diagram of operation process for technical object utilising an artificial neural network
Rys. 1. Schemat procesu obsługiwania obiektu technicznego wykorzystującego sztuczną sieć neuronową

2. Model of a repairable technical object

Determination of the maintenance function of a technical object can occur on the basis of a functional and diagnostic analysis. A diagnostic study of a technical object is the domain of the reliability theory, diagnostics and operation of technical objects. The issue of the determination of maintenance information is a complex process. This process begins with recognition of the properties of the object in question, the nature of its work and a development of its functional and diagnostic (maintenance) model.

It is only on a further stage that the object's diagnostic structure is determined, which constitutes the object's internal structure including a diagnostic description. The final state of this process is the obtained internal structure of the object, which is adapted to the realisation of the maintenance (prophylactic) process. The issue of the diagnostic study of a complex technical object described in [1, 2, 3, 4] constitutes the basis of the process of the location of defects and an assessment of the object's state.

While preparing a diagnostic model of this class of object, its internal structure was divided into four levels of maintenance structure (Fig. 2): level one – object, level two – assemblies in object, level three – subassemblies (in each assembly $\{E_i\}$), level four – modules-basic elements (in each subassembly of each assembly of the object).



Diagnostic knowledge base of the object

Vector of initial diagnostic signals $\{X(e_{i,j})\}$				
$X(e_{1,1})$	...	$X(e_{i,j})$	...	$X(e_{i,J})$
$X(e_{1,1})$	...	$X(e_{1,j})$	...	$X(e_{1,J})$
⋮	...	⋮	...	⋮
$X(e_{i,1})$	...	$X(e_{i,j})$	...	$\varnothing$
⋮	...	⋮	...	⋮
$X(e_{I,1})$	...	$X(e_{I,j})$	...	$X(e_{I,J})$

where: E_i – ij[th] functional assembly in the object, e_i – j j[th] subassembly or functional element in a given assembly, $Y_{1,2,3}$ – input signals in the object.

Fig. 2. Functional and diagnostic model of the object
Rys. 2. Model funkcjonalno-diagnostyczny obiektu

Each functional subassembly of the object consists of basic elements, which are the smallest and indivisible functional element in the object. It was assumed in the paper that such an element is understood as a basic element in the object where there is an output (diagnostic) signal on its output. If object has been divided into *i* structural levels, and in each of them, there are *j* basic elements, then each of the object's structural levels constitutes a set of operating elements $\{e_{i,j}\}$, which was presented in the form of the following dependence:

$$\{O\} \Rightarrow (\{E_i\} \Rightarrow \{e_j\}) = \{e_{i,j}\} \tag{1}$$

where: $\{O\}$ – object's internal structure, $\Rightarrow$ – relation of result (division), E_i – i^{th} functional assembly of the object, e_j – j^{th} subassembly in i^{th} assembly of the object, $\{e_{i,j}\}$ – set of basic elements in the object (structure of the object).

The division of the object's internal structure $\{e_{i,j}\}$ accepted in the paper explicitly defines the depth of penetration into this structure. The accepted division is considered to be sufficient if we distinguish the basic module-element in the structure of the object. One of the purposes of the functional-diagnostic analysis is the determination of the object's state. The object's state is determined on the basis of an examination of the set of output (diagnostic) signals $\{X(e_{i,j})\}$(Table 1) [1, 4, 5, 6, 7]. The set of its functional elements $\{e_{i,j}\}$ determined during a diagnostic study of the object constitutes the basis for the list included in the table of a set of diagnostic signals (Table 1).

Table 1. Table of object's input diagnostic signals
Tablica 1. Tablica sygnłów diagnostycznych obiektu

Object	Level of object E_i	Vector of initial diagnostic signals $\{X(e_{i,j})\}$				
		$X(e_{1,1})$	...	$X(e_{i,j})$	...	$X(e_{i,J})$
O	E_1	$X(e_{1,1})$	...	$X(e_{1,j})$	...	$X(e_{1,J})$
	⋮	⋮	...	⋮	...	⋮
	E_i	$X(e_{i,1})$	...	$X(e_{i,j})$	...	$X(e_{i,J})$
	⋮	⋮	...	⋮	...	⋮
	E_I	$X(e_{I,1})$	...	$X(e_{I,j})$	...	$X(e_{I,J})$

where: $X(e_{i,j})$ – diagnostic signal of j^{th} element in i^{th} assembly.

The basis for all maintenance activities upon the object is the analysis of the object's structure and its diagnosis. As a result of the analysis of the object, a set of checks is usually obtained. Most commonly, it is presented as a table of checks or a table of states (i.e. Tab. 1) [1, 2, 4, 7, 12, 13]. Further, the table of states usually needs to be optimised at first. For the purpose of work, it has been assumed that table of states of the object (Tab. 2) represents the fundamental set of maintenance information, so it is a basis for further analysis. The substance of initial expert's actions is to sort the minimum set of checks out of the set of all checks available in order to assure the realisation of state control and/or damage localisation. Choosing the specific approach for the realisation above is called minimisation of set of checks.

Table 2. Table of object's states
Tablica 2. Tablica stanów obiektu

State of object	State of module	Vector of states of elementary components ($e_{i,j}$)				
		$\varepsilon(e_{1,1})$	...	$\varepsilon(e_{i,j})$	...	$\varepsilon(e_{i,J})$
$W(\varepsilon_1(O))$	$W(\varepsilon_1(E_1))$	$W(\varepsilon(e_{1,1}))$	...	$W(\varepsilon(e_{1,j}))$	...	$W(\varepsilon(e_{1,J}))$
⋮	⋮	⋮	...	⋮	...	⋮
$W(\varepsilon_o(O))$	$W(\varepsilon_n(E_i))$	$W(\varepsilon(e_{i,1}))$	...	$W(\varepsilon(e_{i,j}))$	...	$\varnothing$
⋮	⋮	⋮	...	⋮	...	⋮
$W(\varepsilon_O(O))$	$W(\varepsilon_N(E_I))$	$W(\varepsilon(e_{I,1}))$	...	$W(\varepsilon(e_{I,j}))$	...	$W(\varepsilon(e_{I,J}))$

where: $W(\varepsilon(e_{i,j}))$ – value of state assessment logics for element "j" within "i" module of the object.

3. Preparation of the set of the elements of the object's maintenance structure

The methods for the minimisation of the set of checks presented in [1, 4, 5, 7] impose specific requirements for the set of elementary components. An elementary component can have any number of signal inputs but only one output. In the determined set of the object's functional elements, only those elements will be used during the maintenance whose states required repair. For this purpose, a relation for the comparison of the states of the object's elements included in (Table 1) with their standards was developed in accordance with the following:

$$\left(\underset{e_{i,j\in\{E_i\}}}{\vee} W\left(\varepsilon\left(e_{i,j}\right)\right) \mapsto \underset{e_{i,j\in\{E_i\}}}{\vee} W_w\left(\varepsilon\left(e_{i,j}\right)\right) \right) \Rightarrow \underset{e_{i,j\in\{E_i\}}}{\vee} W\left(z\left(e_{i,j}\right)\right) \tag{2}$$

where: $W(\varepsilon(e_{i,j}))$ – the value of state assessment logics for j^{th} element within i^{th} module of the object, $W_w(\varepsilon(e_{i,j}))$ – the standard value of state assessment logics for for j^{th} element within i^{th} module of the object, $W(z(e_{i,j}))$ – the resulting value of the state assessment logics for for j^{th} element within i^{th} module of the object, $\mapsto$ – comparison relation, $\Rightarrow$ – resulting relation.

The result of the expert's activity described with dependence (1) is the determination of an initial set of maintenance information in the form of a set of elements that need to be repaired. In the further step, a comparison of the states of the object's elements included in (Table 2) with their patterns takes place. On the basis of the results of such a comparison, an identification of the object's elements with the state value {2} – usability states – is made. Such elements are not subject to prevention. They are crossed out and are replaced by the symbol "⊗" in the table.

As a result, an initial set of maintenance information items is obtained and presented in Table 3.

Table 3. Table of initial maintenance information
Tablica 3. Tablica pośredniej informacji obsługowej

The level of maintenance structure of the object	Vector of element's states $z(e_{i,j})$				
	$z(e_{1,1})$	...	$Z(e_{i,j})$	...	$z(e_{i,J})$
1	$W(z(e_{1,1}))$	...	$W(z(e_{1,j}))$	...	⊗
⋮	⋮	...	⋮	...	⋮
I	$W(z(e_{i,1}))$	...	$W(z(e_{i,j}))$	...	$W(z(e_{i,J}))$
⋮	⋮	...	⋮	...	⋮
I	$W(z(e_{I,1}))$	...	$W(z(e_{I,j}))$	...	⊗

where: $W(z(e_{i,j}))$ – z^{th} value of state assessment logics for j^{th} element within i^{th} module of the object, ⊗ – table's size completion symbol.

During the creation of the export knowledge base, it is necessary to recognise the features of each fundamental element of the object as well as its operating principles and conditions. The expert, while making use of his/her experience in the use of a given class of technical objects, develops a set of possible preventive activities (Tab. 3). For this purpose, it is necessary to describe the method for the classification of elements of the object's maintenance structure.

4. Classification of the elements of the object's maintenance structure of a complex technical object

Control of the quantity of the qualitative usability function (F_C) in the operation process requires, among other things, the recognition and description of an object's internal structure, the nature of its work, etc. In modern systems for the servicing of technical objects [3, 6, 4, 7], with a computer aided organisation of this process, an important role is played in them by specialist (expert) databases. This specialist set of information concerning the object of servicing is determined on the basis of a description of the elements of the object's servicing structure, grouping of them into classes (Fig. 3), and assigning of a specific subset of preventative activities to them, which are characteristic only of a given class of the elements of the structure.

For the description of the elements of the object's servicing structure for a given class, the following properties of the object and its functional elements were used:

a) The nature of the work (subset of characteristics) of the object;

$$H = \{h_{1,1}, ..., h_{i,j}, ..., h_{I,J}\} \tag{3}$$

where: characteristics which describe j^{th} elements in i^{th} functional units.

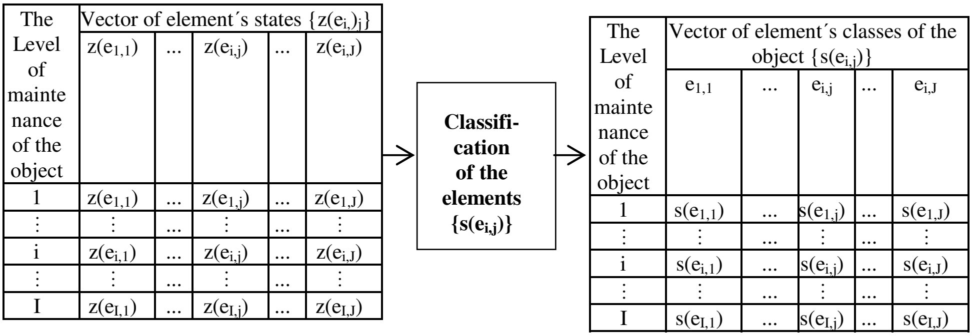


Fig. 3. Scheme of the classification of operational elements of the object
Rys. 3. Schemat klasyfikowania elementów obsługowych obiektu

The subset of information items in the form of dependence (3) represents those basic characteristic functions for the realisation of which this object was constructed, e.g. the parameters of output signals, the turning moment, the power of the engine of the vehicle, pressure in the braking system of the vehicle, etc.

b) The function and the tasks performed (a subset of processes);

$$L = \{l_{1,1},\dots,l_{i,j},\dots,l_{I,J}\} \tag{4}$$

The subset in the form of dependence (4) describes those basic phenomena of energy conversion in the object, as a result of which the processes of the functioning of the object are realised and which enable the performance of those tasks for which the said object was constructed, e.g. for the purpose of a reduction of the temperature of the work of the engine in a vehicle, a cooling system was created, etc.

c) The idea and type of energy conversion (a subset of secondary functions) described in the form of the following dependence:

$$M = \{m_{1,1},\dots,m_{i,j},\dots,m_{I,J}\} \tag{5}$$

The subset in the form of dependence (5) characterises the remaining functions that reflect secondary phenomena. These phenomena create processes that participate in the realisation of the main task, e.g. friction of such parts that cooperate with one another, additional heat emission, impurity of the filter, etc.

d) Operating properties which identify an element in a given class (a subset of specific parameters) presented in the form of the following dependence:

$$K = \{k_{1,1},\dots,k_{i,j},\dots,k_{I,J}\} \tag{6}$$

The subset in the form of dependence (6) serves to characterise the specific parameters of the elements of the object, e.g. resistance, elasticity, permeability, etc.

e) Reliability (a subset of defects) as the following dependence:

$$F = \{f_{1,1},..., f_{i,j},..., f_{I,J}\} \tag{7}$$

The subset in the form of dependence (7) describes those distinguished reliability parameters of functional (component) elements of the object, non-serviceability and their defects, i.e. it describes the output of the properties of the distinguished diagnostic signals in the object outside their admissible and boundary values, e.g. a constant drop of the power of the engine of a vehicle, resistance changes, reduction of the elasticity, changes in the permeability, etc.

The basis in the process of classification of the elements of the object's servicing structure, from among the elements of subsets H, L, M, K and F, is the created set of the characteristic properties of elements in the form of the following set:

$$B = \{b_s\}, \quad s = \overline{1, S} \tag{8}$$

where: s – the number of distinguished subsets of classes of servicing elements

The elements of the set of servicing information in the form of dependence (8) constitute the basis in the process of classification (grouping) of the elements of the servicing structure. Obviously, it is required that the elements of set $\{b_s\}$ include as much information as possible with a small size of the set at the same time. One can say about set $\{b_s\}$ that it is determined on the basis of the following dependence:

$$B = \{b_s \in [H \cap L \cap M \cap K \cap F]\} \tag{9}$$

On this basis, with the use of dependence (9), it is possible to assign the elements of the object's servicing structure to one of the following subsets of their classes (s), where: s = {I – electronic, II – mechatronic, III – electric, IV – electromechanic, V – pneumatic, VI – hydraulic, VII – mechanic, VIII – digital, etc.}

In the process of the determination of expert knowledge, which will be on further stage used for the control of the process of the operation of a technical object, an important issue becomes the problem of grouping of the elements of the object's servicing structure. For this purpose, the elements of the object's servicing structure are subject to a classification into the following groups of classes:

1. ***Electronic elements*** are used for the construction of semiconductor devices. In the object's internal structure, they occur in the form of functional modules as devices that amplify, generate signals, switch, supervise, feed, etc. The elements of this class exhibit a satisfactory reliability and belong to the group of reparable technical equipment.
2. ***Mechatronic elements*** are used in modern systems of supervision, adjustment and control. They are commonly used in technical devices in the form of controlled valves, servo-motors, etc. The equipment from this group is characterised by a conversion of electric energy or any other energy into a suitable form of kinematical or potential energy connected with feed or torque. The elements of this class of objects exhibit a relatively high reliability and belong to the group of reparable technical equipment.
3. ***Electric elements*** are found in technical equipment connected with the conversion of mechanical energy into electric energy (electric generators), or with the conversion of electric energy into mechanical energy (electric engines). They also perform the function of elements that preserve and transmit electric energy. Technical devices of this group work in difficult operating conditions: high temperatures, electromagnetic interaction, etc. The elements of this class exhibit a relatively high reliability and belong to the group of reparable technical equipment.
4. ***Electromechanical elements*** are found in technical devices as components of power supply units, servo-motors, power transmission systems and controlled electromagnetic valves, etc. The elements of this class exhibit a satisfactory reliability and belong to the group of reparable technical equipment.
5. ***Pneumatic and hydraulic elements*** are found in equipment which have to do with the conversion of the pressure energy of gases or liquids into the form of kinematical or potential energy connected with feed or torque. They are also found in such objects as pressure vessels, pressure reducing valves, pneumatic or hydraulic servo-motors, transmission equipment and safety devices. The elements of this class exhibit a high reliability and belong to the group of reparable technical equipment.
6. ***Mechanical elements*** are most commonly used in technical devices in the form of power transmission systems, servo-motors, mechanical valves, couplings, etc. The elements of this class exhibit a high reliability and belong to the group of reparable technical equipment.
7. ***Digital elements*** are found in modern control and adjustment systems. The devices of this class exhibit a high reliability and belong to the group of irreparable technical equipment. Renovation of the elements from this class can be done only through a replacement of a given element with a new one.

The results obtained were presented in Table 4.

Table 4. Classes of operational elements of the object
Tablica 4. Klasy elementów obsługowych obiektu

Level of maintenance structure of the object	Vector of the elements classes of the object $\{s(e_{i,j})\}$				
	$(e_{1,1})$	...	$(e_{i,j})$	...	$(e_{i,J})$
1	$s(e_{1,1})$	...	$s(e_{1,j})$	...	$s(e_{1,J})$
⋮	⋮	...	⋮	...	⋮
I	$s(e_{i,1})$	...	$s(e_{i,j})$	...	$s(e_{i,J})$
⋮	⋮	...	⋮	...	⋮
I	$s(e_{I,1})$	...	$s(e_{I,j})$	...	$s(e_{I,J})$

where: $s(e_{i,j})$ – classes of the elements of maintenance structure of the object {s = (I – electronic, II – mechatronic, III – electric, IV – electromechanic, V – pneumatic, VI – hydraulic, VII – mechanic, VIII – digital)}.

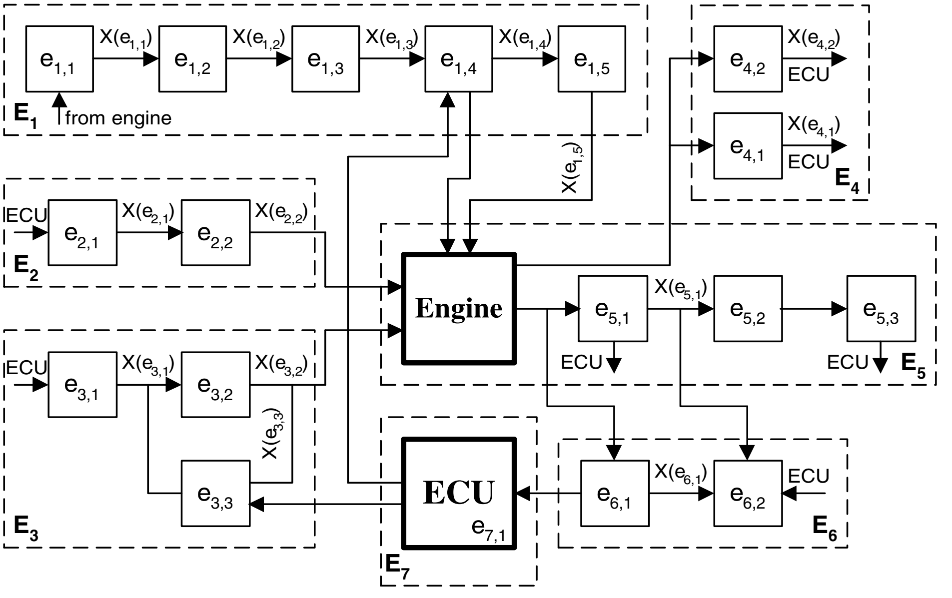
4. Classification of operational elements of a car engine Motronic type

The method for the expert knowledge base [2, 3, 6, 10, 11, 12] determination presented will be verified on the example of a reparable technical object, which is an analogue controller unit for an internal combustion automotive engine with its peripheries. Research set-up was developed on the basis of a spark ignition engine with multi-point injection. The object was subjected to a diagnostic development, as a result of which a functional-diagnostic diagram was developed. In the example, an object was used whose internal structure (Fig. 4) is composed of seven modules (E_1, E_2,…, E_7) (Tab. 2), and each one of them, up to five elements, were distinguished [1, 4].

The internal structure of the object was divided, as a result of which a set of functional elements was determined. The determination of the operating structure of the object was conducted in compliance with dependence (1). The results obtained are presented in Table 5.

The presented method of diagnosing of technical objects requires the use of a uniform compliance of the designation of the elements of the object's structure. For this reason, the basic elements, modules of the object included in its functional and diagnostic model, must be "addressed" in the following manner ($e_{i,j}$), where: j – is the number of the element in a given assembly, and (i) is the i^{th} number of this assembly of the object.

On the further state of the listing (development) of the set of the object's operational information, a classification (grouping) of elements was conducted in order to distinguish classes (groups) of operational elements. With the use of the manner of the 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 6.



where: E_1 – ignition module: $e_{1,1}$ – automotive alternator, $e_{1,2}$ – voltage regulator, $e_{1,3}$ – battery, $e_{1,4}$ – coil ignition, $e_{1,5}$ – sparking plug; E_2 – fuelling module: $e_{2,1}$ – fuel tank ventilation valve, $e_{2,2}$ – fuel injector; E_3 – air-feeding module: $e_{3,1}$ – air flow meter, $e_{3,2}$ – throttle position sensor, $e_{3,3}$ – idle run position controller; E_4 – starting circuit: $e_{4,1}$ – combustion knocking sensor $e_{4,2}$ – coolant temperature sensor; E_5 – power supply circuit: $e_{5,1}$ – oxygen sensor (1), $e_{5,2}$ – catalyser, $e_{5,3}$ – oxygen sensor (2); E_6 – engine block: $e_{6,1}$ – crank shaft position sensor, $e_{6,2}$ – EGR valve: E_7 – $e_{7,1}$ electronic control unit.

Fig. 4. Diagram of an electronic controller for an automotive engine
Rys. 4. Schemat silnika benzynowego sterowanego elektronicznie

Table 5. Internal structure of the object
Tablica 5. Struktura wewnętrzna obiektu

Assembly of the object	Structure of the object $\{e_{i,j}\}$				
E_i	e_1	e_2	e_3	e_4	e_5
E_1	$e_{1,1}$	$e_{1,2}$	$e_{1,3}$	$e_{1,4}$	$E_{1,5}$
E_2	$e_{2,1}$	$e_{2,2}$	∅	∅	∅
E_3	$e_{3,1}$	$e_{3,2}$	$e_{3,3}$	∅	∅
E_4	$e_{4,1}$	$e_{4,2}$	∅	∅	∅
E_5	$e_{5,1}$	$e_{5,2}$	∅	∅	∅
E_6	$e_{6,1}$	$e_{6,2}$	∅	∅	∅
E_7	$e_{7,1}$	∅	∅	∅	∅

Table 6. Classes of operational elements of the object
Tablica 6. Klasy elementów obsługowych obiektu

Class of element $s\{e_{i,j}\}$	Elements of the assembly $\{e_{i,j}\}$						
	E_1	E_2	E_3	E_4	E_5	E_6	E_7
I – electronic	$e_{1,2}$	–	–	–	–	–	–
II – mechatronic	–	–	$e_{3,3}$	–	–	–	–
III – electric	$e_{1,1}$; $e_{1,3}$; $e_{1,4}$; $e_{1,5}$	$e_{2,1}$; $e_{2,2}$	–	$e_{4,1}$; $e_{4,2}$	$e_{5,1}$; $e_{5,2}$	$e_{6,1}$; $e_{6,2}$	–
IV – electromechanical	–	–	$e_{3,1}$; $e_{3,2}$	–	–	–	–
V – pneumatic	–	–	–	–	–	–	–
VI – mechanical	–	–	–	–	$E_{5,3}$	–	–
VII – digital	–	–	–	–	–	–	$e_{7,1}$

5. Conclusions

The process of servicing of technical objects, especially those objects where a short shutdown time is required, must be realised according to a preventative strategy with the control of the state. It is a difficult organisational and technical undertaking. However, an object's preventative treatment organised in this manner is characterised by a relatively high effectiveness obtained chiefly by an optimisation of the costs of operation. At present, expert systems are used for the execution of servicing tasks of technical objects, which make use of specialist's knowledge. The process of obtaining human specialist's knowledge for the support of the preventative treatment of objects is under a constant development. The important aspects of this process include recognition of description of methods to convert this knowledge to a form that can be used by a computer system.

An effective approach in the process of the organisation of servicing systems for technical objects is the use of information from different sources, and especially from artificial neural networks. Nevertheless, it is the human who plays an important role in expert systems of servicing, who determines servicing information, as well as organises and supervises a servicing system.

This paper presents a method to use (transform) human specialist's knowledge for the needs of computer designing of servicing systems for technical objects.

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Klasyfikowanie elementów struktury obsługowej naprawialnego obiektu technicznego

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

W pracy zaprezentowano metodę tworzenia wiedzy ekspertowej, wspomagającej obsługiwanie złożonego obiektu technicznego. Zaprezentowano sposób realizacji opracowania obsługowego obiektu. W tym celu przedstawiono schemat złożonego obiektu technicznego wraz z jego elementami funkcjonalnymi, który stał się podstawą klasyfikowania-grupowania elementów. Opisano metodę przekształcania informacji diagnostycznej i wiedzy specjalistycznej do wymaganej postaci informacji obsługowej. Przedstawiono także znaczący udział eksperta w procesie zestawiania wiedzy ekspertowej. Celem działania ekspertowego jest uzyskanie informacji, która może być podstawą w projektowaniu systemów obsługiwania obiektów technicznych. Wyniki pracy poparto przykładem wyznaczania informacji specjalistycznej o obiekcie.