

New Models of Maintenance of Rotary Machines

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ABSTRACT

The paper provides an overview of knowledge presentation methods and knowledge frameworks. The hierarchical organization of knowledge as well as the apparatus of logical reasoning is defined. A system of expert evaluation was developed together with models of input - output components of the expert system for maintenance of rotary machines.

Keywords: Knowledge, Expert System, Knowledge Frameworks, Reasoning, Knowledge Bases.

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Introduction

Knowledge is the third category (besides "data" and "information") and represents refined information of a more general type than that which can be found in standard databases. Knowledge can be thought of as a collection of related fact(s), procedures, models, and heuristics that can be used in problem solving or in logical reasoning systems. Knowledge can be considered information in context, that is, information organized so that it can be easily used for problem solving and learning.

Knowledge varies widely both in its content and in its appearance. It can be specific, generally accurate, vague, procedural, declarative, etc. Obviously, it is a significant problem to find methods used to organize and place knowledge in computer programs [1].

Artificial intelligence research belongs to the scientific field in which the possibility of training technical systems (machines), such as a computer, to "behave intelligently" is examined.

The two cornerstones of unintelligent behavior of technical systems are the ability to understand natural language, as well as the ability to reason or reason logically.

Artificial intelligence is definitely entering the sphere of decision-making. In expert systems, instead of conventional computer data processing, we encounter the processing of facts or knowledge in various forms, from deep "causal" knowledge to "superficial" knowledge. Instead of strict algorithms, heuristic rules are entered into the computer. Finally, certain forms of "reasoning" are left to the machine - the computer. The most important thing is that these ideas have become easy to achieve. First of all, this was contributed by the incredible development of computer technology with the unimagined possibilities of creating large knowledge bases and constructing single-component reasoning mechanisms.

Expert systems use formal ways of presenting the knowledge possessed by a person - an

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expert and methods of logical reasoning, to provide expert advice or an opinion on a problem that the user is interested in through appropriate computer programs, i.e., an expert system means the establishment within the computer of a part of the skill of an expert, which is based on knowledge and of such a form that the system (computer) can offer intelligent advice or take an intelligent decision in the function that is in progress. So, expert systems aim to provide answers to problems that require reasoning, recognition and comparison of forms, acquisition of new concepts, reasoning, in short, they provide answers to questions that require intelligence. Expert systems can be effectively applied in areas where thinking about a problem is reduced to logical reasoning rather than calculation and where each step in solving a problem has a greater number of alternative possibilities.

In addition to knowledge, an expert system also requires an inference procedure - a reasoning method used to make a connection between the knowledge stored in the computer and the problem posed by the user. It also requires a way to represent knowledge in a computer, knowledge that an expert system should possess, primarily in the form of logical structures that the machine can easily manipulate and a set of appropriate data structures [2].

It is certain that today it is not possible to answer to what degree human experts will be replaced by a computer expert system. In any case, one of the basic shortcomings of expert systems, which it is difficult to expect to be overcome soon, is the lack of interaction, in the way it is realized with a human expert. The user wants to talk to the expert, communicate his concern, hope, love and thus gain confidence in the expert's opinion. On the other hand, there are also situations where the user communicates more easily with the computer because he is free from the fear of authority and the possible misuse of information that he will communicate to a human expert.

Overview of Knowledge Presentation Methods

General Approaches

Production rules are a general method of representing knowledge that is adequate when knowledge is described by actions.

Inclusions are well suited for representing knowledge about objects that can be grouped into classifications such that some categories are subcategories of others. Inclusion hierarchies can be used as organizational schemes in conjunction with other methods such as the predicate method.

Mathematical logic, such as predicate calculus, provides a general and fundamental possibility that supports logical reasoning. However, it hardly supports organizing facts into groups so that knowledge can be used more efficiently. In this sense, mathematical logic can be considered a "low-level" method that deals well with details, but requires integration with other methods of knowledge representation if one wants to build non-trivial systems.

Knowledge frames provide an organizational scheme for representing knowledge. Knowledge scripts have been used on

some experimental systems for understanding natural languages in order to represent scenarios with a standard chronology such as, say, what an individual does when going to the workplace. Knowledge scripts are similar to knowledge frames with the addition of a description of chronology (time-ordered knowledge) [3].

Semantic networks, as well as knowledge frames, serve for the general organization of knowledge or require no special support at the "low level" of knowledge representation: any system in which knowledge modules can be described as graph nodes with weights is a semantic network.

Knowledge constraints represent a relationship between one: two or more objects that can be considered as a predicate. If the emphasis is on the use of constraints in the representation of a set of objects and their connections, then naturally the method of knowledge constraints can be used in the representation of knowledge.

Relational databases can sometimes serve as a knowledge representation method. As they are usually implemented, they are suitable for the manipulation of a large number of structural data in the form of records, but in a previously known and predetermined way.

Production Rules in the Presentation of Knowledge

The production system consists of a collection of "condition - action" pairs called production rules (or decision rules), together with a database of "system states" and procedures for manipulating production rules.

Each production rule contains a condition that must be satisfied before an action is performed. A system state database is a collection of information that is tested to infer the truth of a condition. A rule interpreter is simply a program loop that tests the truth of a rule's condition and executes actions when the condition is true.

Hierarchical Organization of Knowledge

A large part of human knowledge is organized hierarchically. All the things we know something about are grouped into classes or sets. These classes are then grouped into higher level super classes and so on. Classes are identified by the name to which the name is attached. Grouping into classes is based on the ability to recognize different characteristics that are common to all members of the class.

Logic of Propositions and Predicates

In certain situations, mathematical logic is suitable for representing knowledge. Propositional calculus is usually used in theoretical considerations because it is not suitable for building practical systems. Since it is actually a simplified version of predicate calculus, understanding propositional calculus is usually the first step in understanding predicate calculus. Calculus or predicate logic is often used in the representation of knowledge and is the basis of so-called "logic programming".

The predicate calculus is used because the expressive power of

the propositional calculus is rather modest and does not allow consideration of the objects that enter the propositions. Predicate calculus enables working with both objects and positions and is a standard method of knowledge representation based on mathematical logic.

Expressions in the predicate calculus are similar to those in the propositional calculus, to which detailed descriptions of objects have been added.

Predicate calculus is a convenient method of representing knowledge if there is a suitable set of functions and predicates available for building formulas.

Using resolution principles, unification operations, and other logical techniques, predicate calculus provides a very powerful method of representing knowledge and bases.

Knowledge Frameworks

Knowledge frames are a collection of information and rules concerning a given object, situation, or concept. Each frame of knowledge contains a large number of information, and the knowledge base consists of a large number of frames. Some frames are permanently stored in the knowledge base while some dynamically appear and disappear during the problem-solving process. Structurally, knowledge frames consist of two parts: the name of the frame and the list of pairs.

The very name frame of knowledge indicates that this construction aims to delimit, frame a part of knowledge from general knowledge, that is, to group facts and rules that are relevant to the given context of consideration. Rules can be relatively easily combined with knowledge frames in such a way that they can be used as methods attached to knowledge frames.

Due to the fact that knowledge frames emphasize the object (frame) as a basic construction in solving problems, that is, procedures (methods) are actually features of frames, this approach is identical to oriented modeling [2].

Semantic Networks

Inclusion hierarchies can be easily generated by adding new types of relations, i.e. arcs and nodes to the graphical representation. This kind of generalization is called a semantic network. The concept of access to knowledge through the "accrutation" of nodes in the semantic network of movement through arcs is in some way analogous to the activity of the brain through the transmission of electrical signals through neural networks.

The practical advantages of semantic networks are very little redundancy of knowledge because each object, i.e. the knowledge related to it, appears only once in the network. This achieves significant cost savings and increases the integrity of the knowledge base. Also, given that all associations between objects are explicitly shown as arcs in the network, searching the knowledge base is in principle very efficient.

Unlike the predicate calculus, there is no standard type of semantic network, that is, a standard method of logical

reasoning. Certain standardization can be introduced if the so-called concept of semantic primitives is used, let's say they can be entities such as: a person, a thing or a part of an entity; actions such as: fly, be, want, etc.; qualifiers such as: well, much, etc.; type indicators and the like.

Rule-based Expert Systems

Apparatus of Logical Reasoning

In order for the inference apparatus to be able to start the logical reasoning process, it is necessary to first set the so-called reasoning goal and initialize all the facts necessary for testing the conditions, i.e. executing the appropriate actions. Initialization is done with the help of values found in the fact base or it can be done interactively, with the fact that then the reasoning apparatus asks the user a question during the session of using the expert system. For the effective realization of the dialog with the user, it is necessary that the inference apparatus offers the user the type of legal answers that are allowed for the inspiration of certain facts and thus guides the user in the direction of providing answers that the system understands.

Considering the goal of logical reasoning, i.e. the goal of consultation expected from an expert system, two general approaches are possible:

- direct reasoning;
- inverse reasoning.

Direct Reasoning

Direct reasoning, sometimes called "chain of inference in advance", is based on the idea that each rule is tested starting from a condition (or premise) and is not executed until the corresponding condition becomes true. So, if the condition of the given rule is not correct, its action is not executed at the moment but moves on to the examination of the next rule. An abandoned rule is examined again in the next pass through the rules. By executing the action of one rule, the state of the condition of another rule is actually changed in such a way that this condition can become true. This is only possible if the facts in the given condition are the consequence of actions from some other rules. During the examination of conditions, it is possible to come across a condition for which it is impossible to determine its logical value because in the system state database it is not possible to find values for the facts that participate in the formulation of the condition.

Inverse Reasoning

Inverse reasoning, also called "backwards locking chain" or "target reasoning", is based on the idea that rules are considered starting from the action or conclusion. On this occasion, it starts with the rules (which contain the locking goal as their conclusion. In this way, in fact, the set of rules is divided into subgroups that need to be examined in order to reach the desired goal of inference, thereby significantly narrowing the search space and reaching the goal of inference in a shorter time.

Just as in the case of direct reasoning during the examination of conditions, it is possible to come across a condition for which it is impossible to determine its logical value for the facts involved in the formulation of the condition.

Analysis of the Composition of the Knowledge base of the Expert System

The composition of the knowledge base consists of data banks, procedure banks and databases and procedures. The database and procedures consist of modules for coding, search and auxiliary modules.

The following methods of knowledge representation are mainly used:

- first-order predicate calculus where knowledge is represented in a formal mathematical language using the standard theory of mathematical logic;
- associative networks where knowledge is represented by directed semantic graphs as a semantic network, which is one of the generalizations of standard graph theory;
- derivation rules where knowledge is represented by derivation relations (rules), most often using the theory of formal grammars, which is the easiest to implement due to the relatively simple presentation of recursively written facts in lists, and therefore the most used [3].

Composition for Decision Making

The decision-making system consists of a hypothesis-setting module and a hypothesis-testing module. Probable hypotheses are created based on searches of data banks and procedures. If the hypothesis exists in the knowledge base, the facts and procedures related to it are compared with the input data. The first way is theoretically acceptable, but very difficult for consistent application. The second way is theoretically problematic, precisely because of the indeterminism that appears. They are much easier to apply in practice, which is why the expert system of that type of decision-making prevails, and recently attempts have been made to apply a combination of both types of decision-making.

If the hypothesis is accepted, the results of its verification in reality are entered into the knowledge base. It can be said that this part of the expert system is standard today, i.e. all ES use the same algorithms [4].

Input-output Modules

The input-output composition is completely dependent on the purpose of the expert system (ES). It consists of communication, preprocessing, postprocessing and analyzer modules. In addition to being in charge of input - output data, it performs preprocessing and analysis of input data as well as additional processing of output data. With "off-line" ES input - output composition is relatively simple. The input is usually text data that the user provides via the keyboard and the results of previous "off-line" measurements recorded on a suitable medium. The output is textual data and graphics. With "on-line" ES input - output composition, in principle, represents a critical link of the system. There are three levels of such "on-line" ES:

- diagnostic, whose input-output composition collects current "ideal-time" data in a certain time interval, on the basis of which they try to find the causes of the process (most often errors) and advise the necessary actions;
- supervisory, whose input-output composition continuously collects "real-time" data that is further analyzed and

interpreted, and if necessary, warnings are given if a critical situation arises;

- control, whose input-output composition continuously collects "real-time" data that is analyzed and it is decided what actions the input-output composition should undertake [5].

Expert Systems for Machine Maintenance

Building an Expert System for Machine Maintenance

In general, an expert system is defined by certain characteristics [1]:

- the expert "feeds" the computer with knowledge from a certain field, in the specific case - the field of maintenance;
- since the majority of that knowledge is recorded using sentences, as opposed to mathematical equations, the computer system must process symbolic data, as opposed to numerical data;
- knowledge recorded in an electronic computer is divided into three categories: facts, assumptions and heuristic rules. Heuristic rules connect facts and assumptions about that area in the form of a problem, and then try to find a solution to that problem;
- when knowledge from a given field is stored according to the appropriate scheme, information about the problem to be solved is placed in the computer. Heuristic rules are then used to link the knowledge to the problem or vice versa. Finally, the computer suggests a solution or provides a report that can be used to determine a solution.

Combining these features leads to the following definition: an expert machine maintenance system is a computer system with sufficient hardware capabilities for programs that do the following things:

- the knowledge base is stored in the computer memory. A knowledge base can contain knowledge in any form, but usually contains a set of rules in the format: IF THIS... THEN THAT;
- there are several schemes that are used to enable the description of the problem by a human and the entry of the problem into the computer system;
- the so-called A "reasoning machine" or rule interpreter connects the knowledge base and the problem in a way that mimics human intelligence. This is a critical factor, because such a program must perform the same task as an expert who, after listening to a description of the problem by a human, would come to the solution of the problem using certain expertise. Expertise may include the use of expert common sense, specialized knowledge, complex skills or intuition;
- the so-called the user interface displays, prints, draws or transmits the solution to the problem in a way that is understandable to the user but so that it can be used on another machine [3].

The expert system for machine maintenance is also a computer system with knowledge bases. These systems can be successfully used, for example, in machine diagnostics because they are able to very quickly, on the basis of a software package, examine, compare, select, check a large number of data and, for example,

diagnose the state of the machine (system). If the specialist - the diagnostician wants to know on the basis of which such a diagnosis was given, the expert system will give the way in which he concluded it.

The expert system for machine maintenance (figure. 1) can have several modules, namely:

- designing a technical system for machine maintenance;
- design of maintenance technology (non-periodic inspections, control inspections, technical diagnostics, lubrication, repairs - small, medium and general, search for and removal of weak points);
- computerized maintenance management.

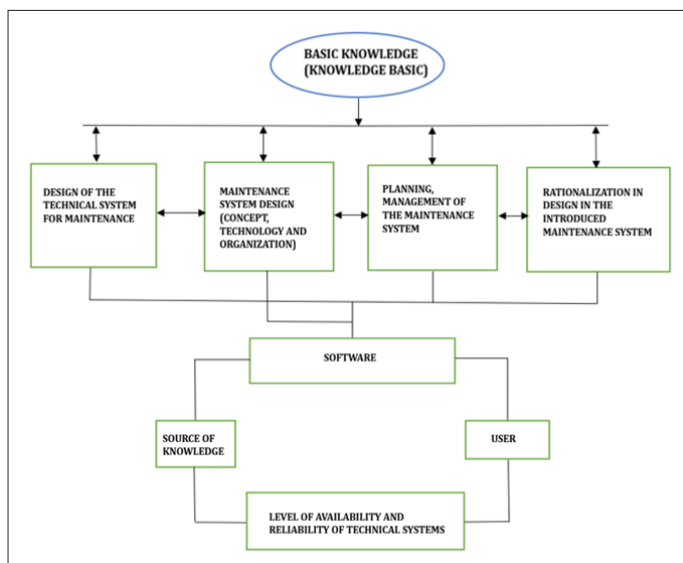


Figure 1: The structure of the expert system for machine maintenance

The basic problems accompanying the creation of expert systems for machine maintenance in industry are:

- how to present the best knowledge, i.e. organize in the computer so that when solving the problem, it is understandable to the user, that it is possible to simply supplement, modify and verify it;
- what kind of inference mechanism needs to be built in order to enable successful problem solving (answer to the question) so that the inference process is understandable to the user, i.e. that it is possible to clarify it en masse.

A technical system (machine) capable of automatic diagnosis and repair must also be self-healing. At this moment, the most realistic approach is diagnostics and repairs using robots and the development of robots for maintenance. A system (machine) that includes a maintenance robot can be considered self-healing. Before perfect self-renewal is achieved, the maintenance robots can be operated manually and by remote control initially, so the great advantages are in flexible satisfaction of needs.

The knowledge base is oriented to the specific subject area, and the "shell" is built completely independently and is applied for the specific subject area with minor changes.

Expert systems are used in the "soft" area, ie. where incomplete and unreliable data are used.

In addition to the ability to solve problems, the expert system must be able to explain its decisions to the user, that is, its conclusions that made such decisions possible.

The knowledge base is dependent on the area of use, but the "shell" is not. That is why it is possible to use the "shell" in principle to build various expert systems, so that we incorporate a new knowledge base into the "shell" every time. To develop the "shell", the following steps must be performed [4,3]:

- choosing a formalism for presenting knowledge (usually production rules);
- developing the formalism of reasoning;
- developing a user interface (interface) that contains a mechanism for explaining decisions and interpretation;
- developing methods for taking into account unreliable and unnecessary knowledge.

The »shell« of expert systems should check the data itself, look for and correct logical errors, answer questions by searching the appropriate knowledge base.

In connection with the development of expert systems for maintenance, the process of introducing knowledge is particularly important.

The traditional procedure of entering knowledge into the computer is for the maintenance technologist to try to obtain knowledge from professional books on the field of use and from conversations with experts for that field of use, to extract general, explicitly formalized rules that make up the field of knowledge (Figure. 2).

Many expert systems have been built in this way. However, the process of entering knowledge into the computer has become over time the longest and most expensive phase in the development of expert systems.

Because of all this, the development of a system for automated synthesis of knowledge was started. The technical basis for this is automatic learning.

Representation of knowledge for the development of most expert systems most often uses the form of associative triplets: object (entity) - attribute - meaning. This way of presenting knowledge is based on production rules. The left part of the production is a predicate over the associative triple, and therefore every condition in the left part has three components: predicate function, object and attribute [6].

The input conditions are also defined by the left part of the production rules and are described by conjunction, while the independent conditions can have an arbitrary combination of disjunction and conjunction.

The right part of the rule or action contains one or more conclusions that can be executed when the conditions are met.

Each production rule is a "quantum" of knowledge that is stylized in the form of IF ... THEN and which enables, on the one hand, the realization of a logical conclusion and, on the other hand, the development of a specific language of communication that is close to an expert.

Production rules make it possible to define relations that can be of logical and empirical type.

Logical relations are characterized by the so-called »hard knowledge«, »hard« because it is the absolute truth. Empirical relations are defined as "soft knowledge" because it is necessary to define the probability of their occurrence, ie. knowledge is not well formalized and allows for a great possibility of subjective reasoning.

From this consideration, it can be concluded that two basic problems follow the development of expert systems for maintenance, namely [7]:

- how to present the best knowledge, i.e. organize in the computer so that when solving the problem, it is understandable to the user, that it is possible to simply supplement, modify and verify it;
- what kind of inference mechanism needs to be built in order to enable successful problem solving (answer to the question) so that the inference process would be understandable to the user, i.e. that it is possible to explain it mentally.

Expert Evaluation System

The expert evaluation system represents a set of all measures and activities related to the determination of criteria for the application of expert evaluation, the determination of evaluation criteria and methodology, the establishment of a system of experts, the establishment of the necessary information system, all with the aim of ensuring a higher quality of decision-making when making systemic solutions and decisions of special importance [1].

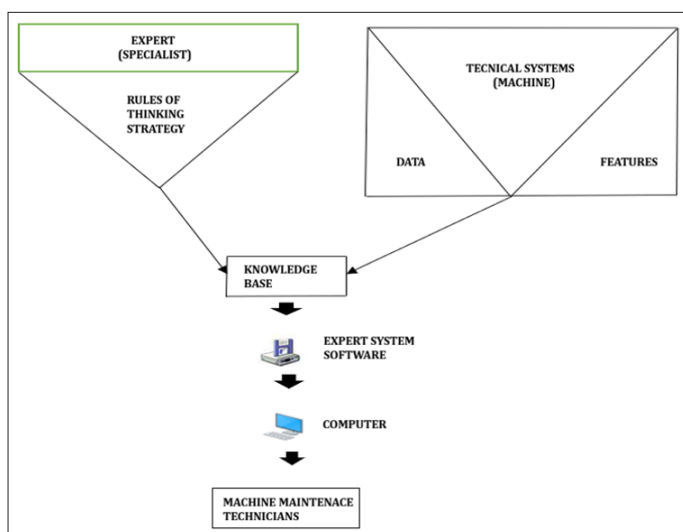


Figure 2: The structure of the expert system for machine maintenance

The basic principles for the successful application of expert assessment are independence in work, the existence of a formalized assessment methodology and the availability of a sufficient number of experts in the given field. A well-organized and professionally implemented system of expert evaluation brings significant effects in terms of their correct selection in the initiation phase as well as in terms of providing optimal solutions in the implementation phase.

The most general goal of expert evaluation is to contribute to a higher quality decision, and this is the common goal of expert evaluation. Differences, however, arise due to the character of research goals, where the main goal and criterion is the contribution to ability (OS) and the character of the research goals, where the goal and criterion is scientific and social contribution.

The basic criteria for expert evaluation are:

- economic justification;
- availability of resources;
- feasibility of the program;
- the relationship between the implementation time and the results obtained;
- production justification;
- possibility of wider application;
- possibility of commercial success.

As part of the economic justification, it is necessary to consider the costs of performing one task and the cost-effectiveness ratio. These criteria should provide an answer to the question regarding technical and economic success.

The availability of resources is a criterion that should enable insight into the availability of potential in terms of personnel, experience, technology, materials (elements, assemblies, devices, subsystems) and integral logistical support.

The production justification criterion refers to the determination of the ratio of development costs and production costs, acquisition costs and production costs, investment costs and production costs, as well as the ratio of domestic substance costs and imported substance costs.

Within the methodology of expert evaluation, the following elements should be defined [1,2]:

- phases in which evaluation is carried out (initiation phase, implementation monitoring phase and success evaluation phase);
- authority to initiate and conduct assessments;
- management levels to which evaluation results are submitted;
- the procedure that will be applied for the assessment;
- possible decisions such as: 1) accept, 2) stop, 3) increase financial investments, 4) reduce financial investments and 5) reprogram.
- How to use own and other information systems;
- The need to evaluate simulation and functional models [8-11].

Conclusion

Expert systems represent a new generation of software for modern automated factories.

The reasons for their application in maintenance (and for the application of artificial intelligence) can be expressed by the following fact:

- applications for a higher level of intellectual work, classes of expertise;
- requirements for complex decisions based on a large number of alternatives, often based on incomplete knowledge;
- requests for complex "on-line" information in a "paperless" factory;
- requirements for a high level of coordination at all stages of technical maintenance (and the production process);
- the form and characteristics of expert systems for diagnostics derive from the following requirements:
- to minimize the probability of not making a diagnosis,
- reduce the diagnosis time to a minimum,
- perform the integration of knowledge, historical data of machine operation, knowledge based on physical laws, knowledge based on functional description and machine operation,
- understanding of different types of problems,
- comfort of resources and limitations,
- the possibility of expanding and maintaining the knowledge base,
- the possibility of using meta knowledge (general models for the analysis of dismissals, etc.).

Expert systems for the diagnosis and maintenance of machines are based on different classes of recognition, which in the functional structure of the diagnosis system are elements of the fundamental blocks of knowledge. Diagnostic recognition refers to:

- recognition classes (objects, operations, characteristics);
- relations between classes - relations that establish relations between objects and operations;
- space of recognition.

The recognition space can have three levels:

- the level of the real world that refers to the area of origin and corrective actions of the diagnostic problem,
- the level of the perceptual world on which diagnostic information is edited and diagnostic conclusions are made,
- the level of the reflective world that refers to the intuitive models of man or artificial symbols.

The construction of an expert system is carried out on the line of communication: maintenance expert - knowledge engineer - computer. Thus, the knowledge engineer is a bottleneck in the relationship between experts in the field of diagnostics (and maintenance) and the computer for which he needs to formalize, for example, the expertise of diagnostics of a part of the machine.

One of the important issues is the acquisition of knowledge. It is a process of transfer and transformation of knowledge about some expertise (for example, about maintenance according to the condition, according to the vibration level of a component part of the machine).

The basics for building an expert system for diagnostics and maintenance are:

- gained experience in building the previous generation of expert systems for maintenance, especially in the field of diagnostics;
- development of the theory of designing and building expert systems for the field of technical diagnostics;
- application of new principles and knowledge engineering with the aim of creating expert systems for this area;
- intensive development of the theory of designing technical systems.

The first stage of construction is identification, which conditions further work on constructing an expert system. It defines the following groups of questions and answers to them: who are the participants and their role in the development of expert systems, characteristics of the problem being analyzed, resources and goals.

Based on the concepts defined in the previous phase, the structure for the organization of knowledge is designed through the formalization phase. It includes three important factors: hypothesis space, process modeling, and data characteristics.

The application (execution) phase includes the prototype of the expert system, which means that the knowledge base is also built, that is, the model for presenting knowledge is defined.

For the presentation of knowledge in the expert system for maintenance and diagnostics in artificial intelligence during the creation of expert systems for maintenance. These include: consistency (whether the methods provide all meaningful distinctions between the concepts they represent); representation of structures; computing efficiency; convenience for modification; conciseness; uniform representation.; logical integrity; adequate search capability (forward, backward, combined, heuristic search).

The last stage in the development of an expert system for machine maintenance consists of experimental exploitations. In this final phase of system development, the system is tested on a real example. On the basis of the feedback effect, the test results can lead to changes, additions, refinements, as well as reformulations of requirements on the basis of which new structures for the organization of knowledge of built-in expert systems for machine maintenance in industry are conceptualized and designed.

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