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IMPLEMENTATION OF EXPERT SYSTEM IN KNOWLEDGE MANAGEMENT IN MECHANICAL ENGINEERING ENTERPRISES

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The paper presents the concept of an expert system supporting knowledge management. The rule-based expert system (RES) uses original, proprietary solutions: a self-organizing Horn clauses table, which simplifies editing and recording of knowledge bases as well as conversion and deduction expert spreadsheets - combining the possibilities of a spreadsheet (algebraic models) with forward deduction expert system, (logical models). The proposed system can be applied in early warning systems and risk management.

Keywords: knowledge management, expert system, network knowledge system

1. Introduction

A considerable number of industrial enterprises in mechanical engineering production environment is called in the literature "engineering to order" (ETO). This environment is characterized by unitary or small-batch production realized at individual customer request. This type of production refers to the products for which the customer requires a specific engineering design, a significant modification or a purchase of new materials. Design and technology are usually developed individually for specific customer orders. They are usually unique projects characterized by specific requirements as far as technical planning, production management, and planning and accounting for the expenses are concerned. The need to create offers for products ordered in small-batches is a common issue here. Such projects are carried out on the basis of initially incomplete data, from the preparation of an offer and its valuation, through developing a budget and a timetable for implementation, to supervision of the execution and settlement of a contract. Repeatability of such contracts is small or even none. Performance of a contract in such an environment requires special support as far as knowledge management is concerned.

As part of a research and development project entitled: "Management support computer system for knowledge management in machine construction industry enterprises" No.: NR03 - 0112 - 10/2010 dated 09.12.2010, an information system is being built in which the authors implement such solutions as Web-based Knowledge System and Rule-based Expert System. These solutions are planned to be used to support activities such as supplier selection, project risk management, early warning system, accumulation of good and bad practices.

In advanced early warning systems it is reasonable to employ knowledge-intensive systems. Two types of tasks can be distinguished for these systems:

- processing power with large variety and complexity,
- integration of different methods and concepts of early warning.

Since creation, processing and use of knowledge is mostly human domain, application of operating computer systems which utilize knowledge encounters many difficulties. There are two main directions of development of such systems [10], i.e.:

- Tools for supporting knowledge management systems (knowledge systems). The aim of these tools is primarily to support knowledge users, i.e. the people involved in knowledge acquisition, creation, recording, structuring, organizing and processing.
- Artificial intelligence (AI) tools [1]. AI tools enable algorithmic acquisition of knowledge (e.g. inductive algorithms, learning systems using artificial neural networks or genetic algorithms) and automatic knowledge processing (for example, deduction systems, universal solvers). The most widely used are expert systems (SE). The value of an expert system is determined by the knowledge obtained from experts by means of knowledge engineering methods which is then transformed into a formal representation [7].

The paper presents the concept of rule-based expert system, which could be used in risk management and early warning systems. In particular, the authors described the simulation of a complex logical structure process to examine the risk of a delayed contract execution (see 2.3) and the prognosis of companies' bankruptcy (see 3).

2. The concept of rule-based expert system (RES) in early warning system (EWS)

2.1. Rule-based expert system (RES)

Rule-based expert system (RES) was developed in two versions: SQL Server for large knowledge bases [3] and MS Excel for individual users with little knowledge bases.

RES rule-based expert system is designed to work with modules of knowledge (e.g., corresponding to a single case of early warning), which can be integrated to create a larger knowledge base. Knowledge in the RES is kept in standard Horn clauses. Those are rules (expert implications) with one conclusion and with their conditional parts being conjunction statements. The conclusion is always a non-negative statement. For example, an implication:

If $(a \wedge b) \vee (c \wedge d)$ then e,

is presented by two Horn clauses:

If $(a \wedge b)$ then e,

If $(c \wedge d)$ then e.

Conditions and conclusions in those rules are logical sentences (not predicates), therefore they have no variables. That approach simplifies the architecture of an expert system and facilitates stability of its functioning. The conclusion process does not suffer from combinatorial explosions and looping, provided its rules are not externally contradictory.

Knowledge Base can be a multi-level structure (Figure 1). The system recognizes the level and type of statements, i.e.:

- askable conditions, that is level zero statements, these statements are not conclusions of any rule;
- final conclusions, or statements that do not appear in the conditional part of any rule;
- indirect conclusions, or statements that are simultaneously conclusions of certain rules and conditions of other ones.

Rules and statements may be accurate or approximate. The system uses trivalent logics with the logical values: true (1), unknown (0) false (−1). In case of an approximate logical reasoning (e.g. fuzzy), instead of logical values the statements are attributed Certainty Factors (CF) within the range [−1, 1]. CF factors are also attributed to the rules. CF coefficients of the rules are usually positive, although this is not an absolute requirement of the system. If the statement is absolutely true and certain it corresponds to CF factor = 1. If the statement is completely false and certain, it responds to CF factor = −1. In other cases, the CF factor is an unspecified resultant of accuracy and certainty. In the case of statements, where the CF $\in (-½ , ½)$, it is generally accepted that it is impossible to determine their accuracy or certainty (in three-valued logic: unknown). Despite the many reservations of theoretical nature, in expert systems deducing in approximate logic the concept of CF coefficients is widely used. [2, 4, 5, 6, 9]. This solution is also applied in the RES.

The RES expert system consists of four modules: tools to support interactive editing of knowledge bases, conversion and deduction expert spread sheet, tools for graphical representation of knowledge and visualization of reasoning paths, as well as a module for simulation of complex logical functions.

2.2. Tools for graphical representation of knowledge and visualization of reasoning paths

Presentation of knowledge in graphic form helps one to understand its internal structure and the relationships occurring between rules and groups of rules.

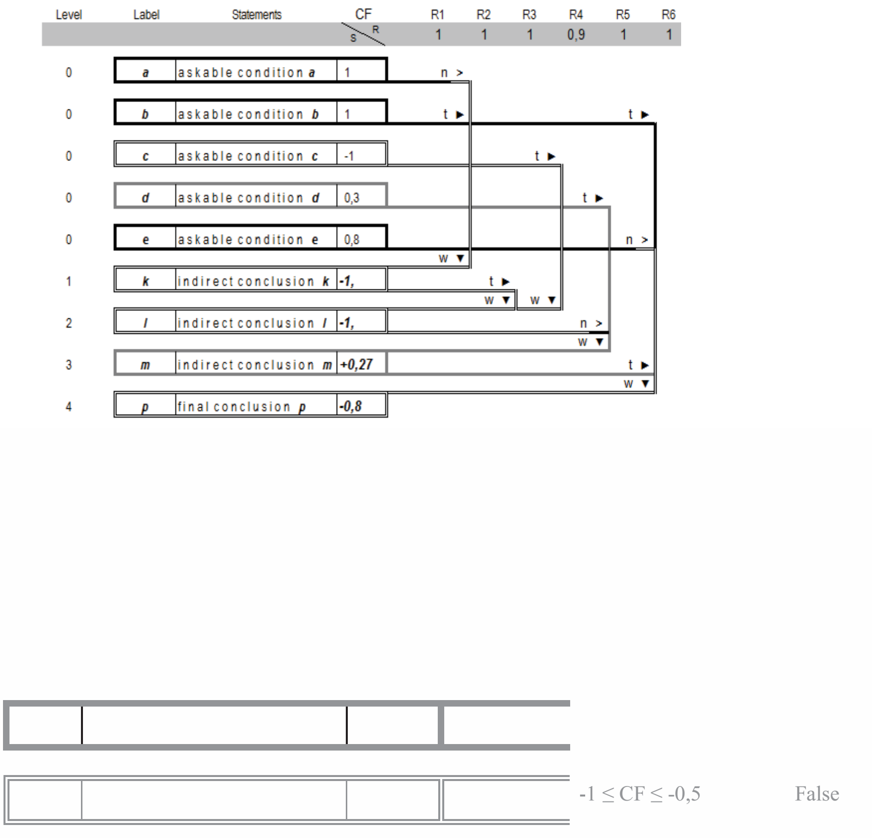


Figure 1. Graphic representation of knowledge and paths of reasoning in RES

RES system creates a graphical representation of knowledge in the form of interactive graphs. Knowledge base and the corresponding graphs are in spreadsheet <Diagram> (Fig. 1). The structure of the graph corresponds to the structure of the expert spreadsheet. The graph not only illustrates the structure of knowledge, but also shows the paths of reasoning (inference schemes) in a format compatible with the values of logic. This solution provides a graphical justification for the derived conclusions.

The user can define the format of paths corresponding to the logical values. Modification of rules (introduction or removal of symbols "t" , "n", "w") will interactively change the structure of the graph. One can also exchange (read and record) the knowledge accumulated in sheets <Diagram> and <Table>.

2.3. Module for simulation of complex logical functions

Simulation procedure cooperates with three spreadsheets: <Table>, <Simulations> and <Calculations>. The logical (static) structure of a simulated process is described in the knowledge base SE contained in the spreadsheet <Table>. However, in most real processes, in addition to logical, there are also other dependencies, in particular:

- quantitative dependencies between numerical attributes (values);
- dynamic dependencies taking into account time delays and accumulation in time. Integrators are elementary systems by means of which most dynamic relationships can be modelled;
- feedback. In static logical dependencies feedbacks are unacceptable external contradictions. Feedback is only possible if there is a battery memory (recovery/previous state memory) of the dependent variables (i.e., conclusions/deductions). Taking into account the previous states causes the appearance of additional state variables. The simulation procedure allows for modelling of feedback because it operates iteratively, so the logical values of deductive conditions are based on the findings of the previous iteration;
- external influences, or extortions - deterministic and stochastic.

Quantitative dependencies, feedback and external influences can be included in the definitions of events. Events are treated as deductive conditions. Occurrence of an event causes that to the relevant deductive condition a logical value <True> is assigned. The spreadsheet <Simulations> contains definitions of events.

In event simulation integrators play an important role. Each integrator is related to input, output and initial condition (IC). The initial condition is set to the integrator output at the beginning of each simulation. The time constant of the integrator is equal to the time unit. During each iteration, the input value divided by the time constant, i.e. the number of iterations per time unit (simulation parameter), is added to the integrator output. It is possible to define three types of events:

- random events. For random events the probability *p* of of an event in a time unit and the maximum and minimum event time (T_{min} and T_{max}) are defined.
- The actual time of the event is determined randomly (the assumed default is uniform probability distribution). After a random choice of an event the simulation procedure randomly determines the time of this event. In case of generating static random events it must be assumed that the number of iterations per unit time is equal to one, and $T_{min} = T_{max} = 1$;
- deterministic events. For these events the duration time is defined (beginning and end) using a time counter expressed in time units. At the beginning of each simulation the value of the counter is reset to zero. In order to define an event dependent only on time, it is necessary to introduce a suitable definition of the formula in the table of events;
- events dependent on the course of the simulated process, that is the state of logical or numerical variables (values). The expressions defining such events can use all the variables in the spreadsheet <Simulations>, i.e. the askable conditions, conclusions, integrator outputs and the timer. In case of more complex dependencies it is also possible to use the expressions, constants and variables included in spreadsheet <Calculations>

Apart from definitions of events the <Simulations> sheet contains also other information, such as:

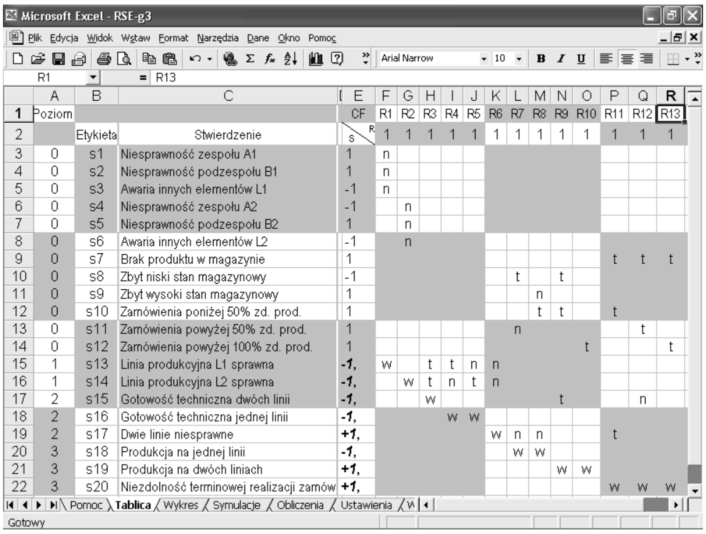
- records of the timing of all process variables - logical variables and numeric variables (values);
- collective results of simulated logical variables, on the basis of which it is possible to create a histogram of events;
- simulation parameter settings. The parameters being: the time of the simulated process, the number of iterations per time unit, and the number of simulations when, due to the occurrence of random events simulation is repeated many times.

If in a simulated process deterministic factors predominate, then it is appropriate to present the process by means of time charts. Among the process variables it is possible to distinguish the following:

- boolean (logical) variables - askable conditions and conclusions;
- numerical variables corresponding to the outputs of integrators;
- additional variables. The user can define up to 20 additional variables of any type.

If the simulated process is dominated by random factors (e.g. simulations using the Monte Carlo method), the simulations are generally repeated several times. In such case, creating time charts would not be justified, but it is advisable to determine aggregate results for boolean variables, such as the relative time of the event, the minimum and maximum time of the event and the data to a histogram representing the distribution of events in different time intervals. This information is contained in the <Simulations> spreadsheet. Time periods of the histogram can be defined in the corresponding cells of the <Simulations> spreadsheet. Detailed information on how to carry out the simulation are given in the sheet <Help> of the RES.

An example of a knowledge base that reflects the logical structure of the production process and the contract shows Fig. 2. Based on the presented simulation was performed according to the risk of delayed execution of the contract.



	A	B	C	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Poziom			CF	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
2		Etykieta	Stwierdzenie	s \ R	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	s1	Niesprawność zespołu A1	1	n												
4	0	s2	Niesprawność podzespołu B1	1	n												
5	0	s3	Awaria innych elementów L1	-1	n												
6	0	s4	Niesprawność zespołu A2	-1		n											
7	0	s5	Niesprawność podzespołu B2	1		n											
8	0	s6	Awaria innych elementów L2	-1		n											
9	0	s7	Brak produktu w magazynie	1											t	t	t
10	0	s8	Zbyt niski stan magazynowy	-1							t		t				
11	0	s9	Zbyt wysoki stan magazynowy	1								n					
12	0	s10	Zamówienia poniżej 50% zd. prod.	1								t	t		t		
13	0	s11	Zamówienia powyżej 50% zd. prod.	1							n					t	
14	0	s12	Zamówienia powyżej 100% zd. prod.	1										t			t
15	1	s13	Linia produkcyjna L1 sprawna	**-1,**	w		t	t	n	n							
16	1	s14	Linia produkcyjna L2 sprawna	**-1,**		w	t	n	t	n							
17	2	s15	Gotowość techniczna dwóch linii	**-1,**			w						t			n	
18	2	s16	Gotowość techniczna jednej linii	**-1,**				w	w								
19	2	s17	Dwie linie niesprawne	**+1,**						w	n	n			t		
20	3	s18	Produkcja na jednej linii	**-1,**							w	w					
21	3	s19	Produkcja na dwóch liniach	**+1,**									w	w			
22	3	s20	Niezdolność terminowej realizacji zamów	**+1,**											w	w	w

Figure 2. Sample knowledge base representing the logical structure of the contract

3. Example of RES application in early warning system (EWS)

To examine the financial situation of entities involved in an engineering industry enterprise, it is possible to use one of the procedures applied in bankruptcy forecasting systems. It is important to assess the financial situation of other enterprises (contributors, customers, suppliers) due to the extensive cooperative relations mechanical engineering enterprises. Bankruptcy forecasting systems are a special category of early warning systems. Below there is an analysis carried out in one of the companies. Information regarding the financial situation result from the designation (based on the enterprise business records) of the parameters in the Frydman procedure. [8]. The logical structure of the aggregation procedure, the path of reasoning/inference and conclusion are shown in Figure 3.

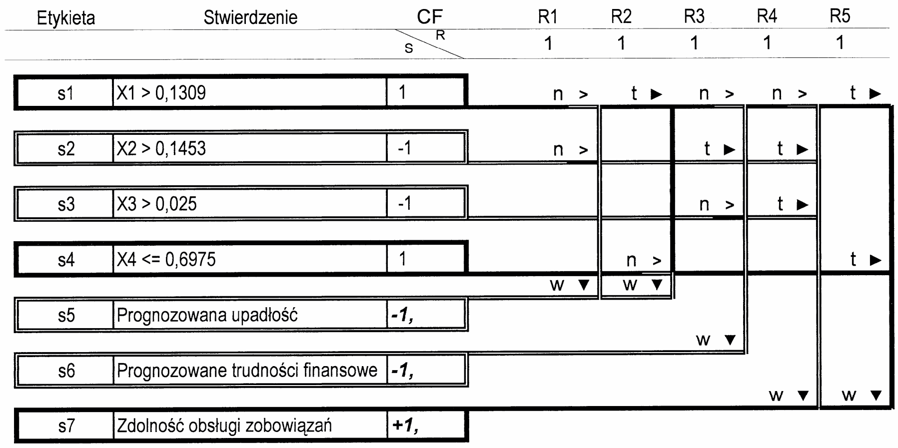


Figure 3. Evaluation of the researched enterprise according to the Frydman procedure – graphic interpretation

In order to verify the information about the absence of risk, for the indicators which determine the absence of risk safety margins have been determined. The conclusion about the lack of risk is usually an R5 rule conclusion for which the askable conditions are s1 and s4 statements relating to the indicators X_1 (maximal) and X_4 (minimal) values (equation 1).

$$\delta X_1 = 100\% \cdot \frac{X_1 - X_{1w}}{X_{1w}} \qquad \delta X_4 = 100\% \cdot \frac{X_{4w} - X_4}{X_4} \qquad (1)$$

X_i – the value of the *i-th* indicator,
X_{iw} – the reference value of the *i-th* reference comparator.

For these indicators the safety margins are:

$\delta X_1 = 176{,}95\%$, $\delta X_4 = 67{,}92\%$.

Given the above safety margin values, the accuracy of the information about the absence of a direct risk due to unfavourable financial situation can be almost certainly confirmed.

4. Conclusions

In the recording and structuring of qualitative information the SSW network system of knowledge is quite helpful. In particular, it is useful to apply Knowledge Objects combining a uniform formal structure with a possibility to use different language representations to describe the factual information. RES, rule-based expert system is practicable in the processing of relatively well-structured qualitative information and the information described by logical-and-algebraic models. In the presented concepts original, proprietary solutions were applied:

- a self-organizing Horn clauses chart, simplifying editing and recording of knowledge bases;
- conversion and deduction expert spreadsheets - combining the possibilities of a spreadsheet (algebraic models) with forward deduction expert system, (logical models);
- tools for visualization of knowledge structure and inference/reasoning paths;
- trivalent logic (True, Unknown, False), that provides monotonic reasoning in developed knowledge bases.

The presented tools will be used in a system supporting knowledge management in engineering industry enterprises which is being built. Both the concept of network-based knowledge and rule-based expert system will be used in the implementation of the following systems: early warning, contract risk management, gathering and sharing knowledge about good and bad practices, supplier selection support.

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