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SUPPLIER CHOICE KNOWLEDGE SUPPORT IN THE SUPPLY CHAIN

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Abstract

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The paper focuses on the issue of choice of suppliers in the market environment. It discusses expert systems as modern methods of its computer support. The issue of supplier choice is presented and viewpoints for the formulation of the decision-making task introduced. The piece of writing furthermore pinpoints the expert character of the solution of this task, making use of the knowledge of experienced professionals. It introduces the principles of fuzzy oriented expert systems as a suitable solution of the task at hand. Language models of the expert systems formalise the high quality mental models of an experienced expert. The global decision-making task is split into partial tasks; the expert modules for their formalisation are integrated into the hierarchic structure. The paper presents the structures of language models and the implementation of the structure of expert systems in the MATLAB-Simulink program environment. Special attention is paid to the issue of supplier flexibility. The efficiency of the decision-making system is proven by the solution of a simulation exercise which represents the classification of two current and two newly contemplated suppliers with various characteristics. The results are analysed and commented on.

Keywords: supplier choice, decision-making task, knowledge system, language model, fuzzy logic, hierarchic expert system

INTRODUCTION

In the last decades the area of computer support of decision-making tasks has seen a significant leap forward. One of the modern trends is also the implementation of unconventional methods of artificial intelligence (neural networks, fuzzy mathematics, expert systems). The methods are based on the implementation of the knowledge of skilled experts. This knowledge thus creates the basis of their high quality knowledge mental models. Knowledge language models of expert systems are then created to formalise these mental models in computing. The usage of expert systems has, in the task of supplier choice solution, a considerable potential.

The main aim of this paper is the analysis of the decision-making task of the supplier choice, leading to the particular sub-tasks and the proposal of the corresponding language models of expert systems. Further aims are the presentation of the current trends in the field of expert system implementation in supplier choice evaluation, the presentation of principles and procedures of the synthesis of fuzzy oriented expert systems for the solution of partial sub-tasks, the integration of a global hierarchical expert system, simulation verification of the function of the system on the example of choice of two existing and two new suppliers, results analysis and the outlook on the direction of further research.

MATERIALS AND METHODS

1 Computational Solution of Decision-making Tasks

The computer support of decision-making processes requires the creation of abstract (program) models of the decision-making situations. When solving this problem, let us contemplate the fact that real decision-making problems can be in high-quality solved by humans – experts in their own fields – using their brain, mental and intellectual cognitive processes.

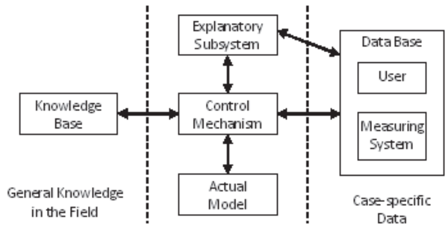
Human decision-making processes are not numerical – when deciding in complex situations, we do not calculate the final result, but we deduce the result in a non-numerical, language-based manner.

When thinking, we use predominantly the words and sentences of the natural language which form the basis of the construction of non-numerical language models of the solved situations. The expert creates these models on the basis of information, knowledge and especially own experience (Buckley, Siler, 2000).

One of the basic features of verbally formalised human knowledge is its vagueness. The first condition for the construction of computer language models is the solution of the problem of the formalisation of vagueness as an uncertainty of verbal terms. The second issue – the construction of logical deduction algorithms capable of making use of vagueness – is solved through the usage of the unconventional multivalue language fuzzy logic approaches (Novák, Perfiflieva, Močkoř, 1999).

1.1 Expert Systems

Expert systemsare specialised computer programs designed to solve special problems which, unlike general problems, require very often highly specialised knowledge – i.e. expert knowledge (Buckley, Siler, 2000) – Fig. 1.



1: *Expert System Scheme*
Source: our own processing

Its core is formed by a knowledge base as a general model of the system. This knowledge base is formed by computer-represented expert knowledge formalised by a set of IF-THEN rules. The update of this general model is done by the input of concrete data for a specific case. The concrete data is represented by a database and can be mined as language values from the user, by direct measurements or by combination of both. The system provides the user with an overview of the knowledge used to solve the specific case. This overview is given via an explanatory subsystem. More complex tasks are diversified into sequences of subtasks which leads to hierarchical expert systems.

The uncertainty, as a concomitant phenomenon of every complicated, hardly describable systems, is in expert systems mostly formalised using the apparatus of fuzzy set theory. Fuzzy sets are a natural and efficient tool for the formalisation of vagueness (Novák, Perfiflieva, Močkoř, 1999).

In this paper expert systems form the basis of logical structure for the solution of the issue of supplier choice when taking their characteristics into account.

2 Modern Trends in Supplier Evaluation

2.1 Approaches and Techniques

There is currently a number of approaches to supplier evaluation. These approaches embody the modern trends and are used by various authors to tackle this issue. Aksoy, Ozturk (2011) give e.g. the following types of analyses: Data envelopment analysis, Cluster analysis, Linear weighting methods (including multi-objective linear programming), Mathematical programming (including Archimedean goal programming (AGP) and Analytic network process (ANP)). Eshtehardian, Chodousi, Bejanpour (2013) state thatthe supplier selection process is a kind of Multi Attribute Decision-Making (MADM) model. The MADM model is the selection model and it is applied for the selection of the most appropriate selection among different alternatives. For solving the introduced supplier selection model, different MADMs methods can be developed such asAnalysis Hierarchal Process (AHP), Technique for Order Preference by a Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW) and Elimination ET Choice Translation Reality (ELECTRE).

2.2 Modernevaluation Criteria

A number of studies (e.g. Araz, Ozkarahan, 2006; Awasthi, Chauhan, Goyal, 2010; Che, Wang, 2008; Razmi, Rafiei, Hashemi, 2009; Shu, Wu, 2009) aims at the description and analysis of the supplier evaluation criteria. Tab. I presents one of these classifications.

The studies mention a number of approaches to the use of evaluation criteria. The authors Bruno, Esposito, Genovese, Passaro (2012) introduce the following hierarchical structure of the supplier choice issue (Fig. 2).

Overall, the criteria mentioned in literature can be divided into four groups: Costs, Quality, Logistic Aspects and Technological Performance.

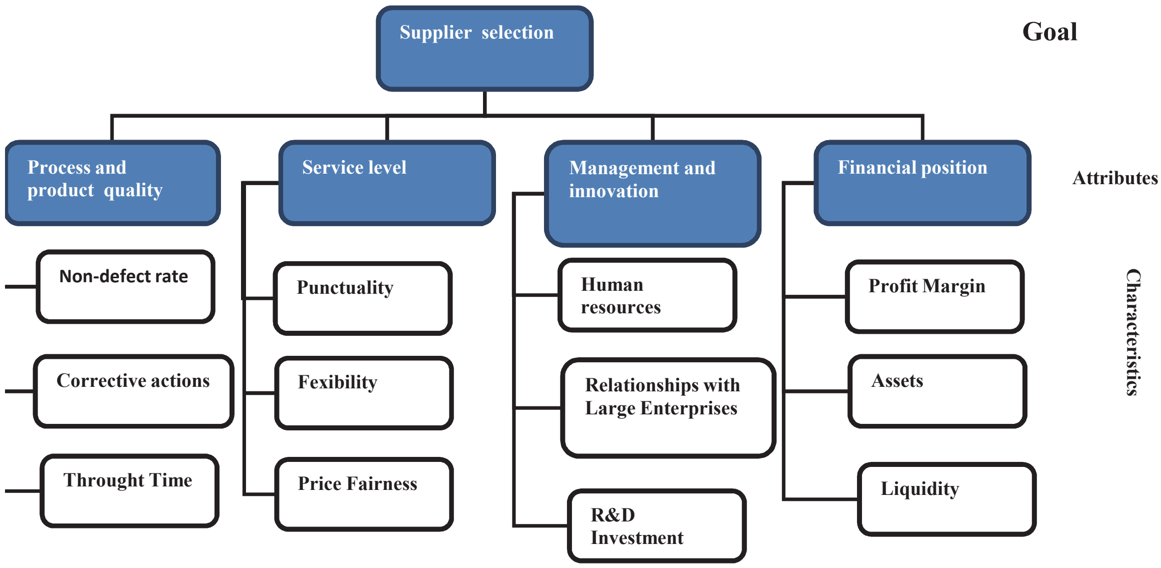
1. Costs

The evaluation process of the potential suppliers on the issue of costs is discussed by the purchasing department and agreed on the basis of three sub-criteria. Here, the unit purchase price is defined as the price of a single item that the supplier charges the company with the added transportation cost (Sencer Erdem, Göçen, 2012). The authors Kumar, Singh, Pal Singh (2013) introduce the

I: *Basic evaluation criteria*

Classification model	Dimension	Criterion
Item	Complexity of supplier market	Entry barriers
		Co-development of product specification
		Market concentration
		Product uniqueness
	Importance of purchase	Environmental contribution
		Alignment with the core competencies of the buyer
		Value-added profile
Supplier	Potential for partnership	Commitment to improvement and cost reduction
		Ease of communication
		Financial capability
		Technical capability
	Delivery performance	Delivery reliability
		Price performance
		Quality of conformance
		Problem resolution

Source: Osiro, Lima-Junior, Carpinetti, 2014



2: *Hierarchical structure of the issue*
Source: Bruno, Esposito, Genovese, Passaro, 2012

group ofcost characteristics: The inputs to this group are inventory level reduction (ILR), lot size reduction (LSR) and reduction in plant stoppage due to shortage of material (RIPS). The output of this group is named Cost Effect. Another approach would be the calculation of the so-called total cost of ownership (TCO). TCO-based models include all costs related to the supplier selection process that are incurred during a purchased item's life-cycle (Aksoy, Ozturk, 2011). Another indicator which could be included in this group is the indicator of financial position i.e. the firm's capacity to generate profits and liquidity (Eshtehardian, Ghodousi and Bejanpour, 2013).

2. Quality

Quality related sub-criteria are evaluated by the production department and the quality department at each facility. Here, the Perfect Order Fulfilment is defined as the level of defective items delivered to the company and it is measured in parts per million (PPM). The quality level of the after sales services is the second issue (Sencer Erdem, Göçen, 2012). The application of quality standards is evaluated in accordance to the existence of a quality department, documentation of quality systems and the commitment of the management to the quality issues. It also includes the environmental concerns of the supplier and is evaluated on the ISO related standards. The corrective and preventive maintenance system is measured in accordance to the number of incidences occurred and recovered by the supplier in the previous periods. The sub-criterion for improvement efforts in quality refers to the supplier's continuous efforts on improving its quality standards (Sencer Erdem, Göçen, 2012). The authors Kumar, Singh, Pal Singh (2013) introduce the criteria group of Quality Characteristics. The inputs to this group are CIPQ (consistency in product quality), IIIC (improvement in incoming components), and RIDCIT (reduction in damaged components in transit). The output of this group is named the Quality Effect. This group also contains the indicator ofProcess and Product Quality: the efficiency and the effectiveness of the manufacturing processes and the quality of the final product (Eshtehardian, Ghodousi and Bejanpour, 2013).

3. Logistics

Logistics related sub-criteria are evaluated by the production planning department. Suppliers are evaluated according to their on-time delivery, order lead time, delivery conditions and packaging standards. Flexibility of Transportation is yet another issue, defined as the ability to transport flexible order quantities. The supplier is more flexible in order quantities if it can adapt to sudden changes in lot sizes. Geographic Distance brings monetary advantage and reduces loss of time in case of a change in the production plan (Sencer Erdem, Göçen, 2012). The authors Kumar, Singh, Pal Singh (2013) introduce a group of criteria named Time Characteristics. The inputs to this group are OTD (on-time delivery), RIOLT (reduction in order lead time), and RIPDCT reduction in product development cycle time. The output of this group named the Time Effect. A part of this group is also formed by the so-called Service Level. Service Level is the punctuality of delivery and the respecting of other contract conditions (Eshtehardian, Ghodousi and Bejanpour, 2013).

4. Technological Performance

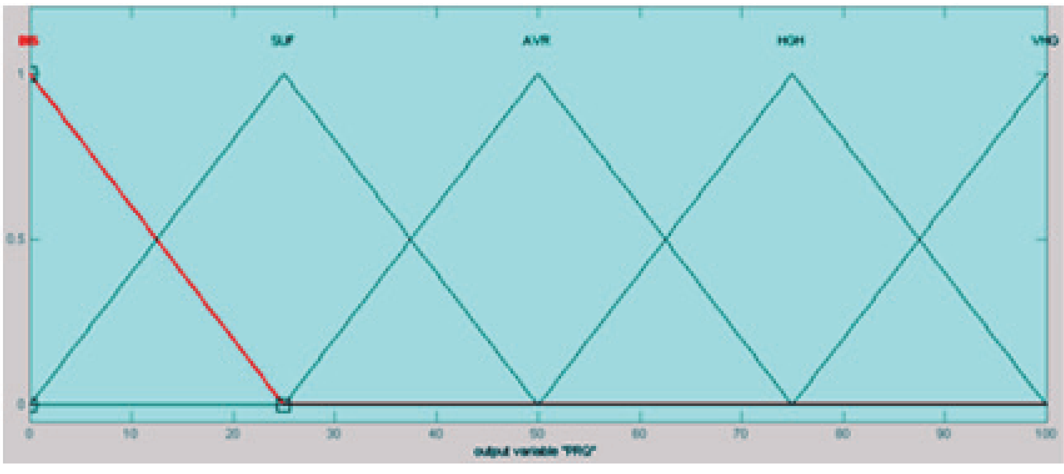
The last main criterion which will be rated by the production department at each facility is the technological performance of the supplier. Allocated capacity is defined as the portion of the supplier's annual production capacity dedicated to the company and a supplier with higher allocation is preferred. Flexibility of capacity is described as the ability to increase the production level due to increases in the demand rate. Flexibility of technology encapsulates the technological requirements for the production line and the support services. Supplier that can adapt their technologies to the changing needs of the manufacturer is preferred. Finally, involvement and potential in new product development defines how dedicated a supplier is to become a real partner and support the company for new product development projects (Sencer Erdem, Göçen, 2012).The paper of the authors Eshtehardian, Ghodousi and Bejanpour (2013) mentions this group under the name of Management and Innovation, i.e. the supplier's attitude towards strategic R & D investments, human resource management and capability of managing relationships with customers.

There are currently several universal supplier evaluation expert systems. One of these is for example the paper of Kumar, Singh, Pal Singh (2013). The next chapter presents a hierarchic expert system with an original approach of the authors.

3 Supplier Suitability Determination Hierarchic Expert System

3.1 Knowledge Language Model Principle

The general model of the solved problem (knowledge base) is not mathematical, but language-based. The *IF-THEN* rule statements are used to formulate the conditional statements that describe the behaviour of the system under modelling. For example the rule expresses linguistic dependency



3: *Variable PRQ – fuzzy sets of linguistic terms in MATLAB*
Source: our own processing

of linguistic output variable *Supplier Quality* (*SUQ*) on two input linguistic variables, namely *ProcessesQuality* (*PRQ*) and *Product Quality* (*PQA*). This is linguistically expressed in the form:

If process quality is high and product quality is sufficient, then supplier's quality is average.

Then, the corresponding rule has the form:

IF (PRQ is HIGH) and *(PQA is SUFFICIENT) THEN (SUQ is AVERAGE)*.

The linguistic values of the input/output linguistic variables are expressed using linguistic terms *"insufficient, sufficient, average, high, very high"*. The linguistic terms are represented as fuzzy sets. Their membership functions are usually expressed using a broken-line triangular approximation (programme system MATLAB – Fig. 3).

The suggested hierarchic expert system contains eight partial expert systems, the language models of which (knowledge base) are based on the abovementioned principles.

3.2 Hierarchic System Structure and Function

The proposed supplier suitability evaluation decision-making expert system is of a hierarchical type and is diversified into 4 partial decision-making levels with 8 partial decision-making blocks ES1-1 to ES 4-1 (Fig. 5).

According to the authors, the basic indicators of supplier suitability are Quality (ES 3-1), Total cost (3-2), Delivery terms (ES 3-3) and Supplier flexibility (ES 3-4). The suggested new method investigates quality from two points of view – Processes quality (ES 2-1) and Product quality (ES 2-2). Processes quality in the supplier company can be described from the following aspects: Processes Audit Results (ES 1-1), Product Certification (ISO), Time on the market and References. The processes audit should be done by a representative of the customer company. The evaluation in this system is fully dependent on the opinion of the expert. The audit proceeds according to the following categories: Communication, Quality control, Technological development, Clean production application. The evaluation according to the mentioned parameters enables a complex examination of the suitability of the particular applicants. The product quality can be examined from two points of view: Compulsory product certification, Processes quality control. The processes quality is evaluated in the course of the control according to the opinion of the expert.

ES 3-2: Total costs: Purchasing value, Transport costs, Costs of packaging, Costs of storage, Costs tariff. The costs are examined separately. This is therefore also the potential improvement – the examination of total costs.

ES 3-3: Delivery terms: Distance to supplier, Delivery time. The authors see these two parameters as interconnected.

ES 3-4 Supplier flexibility: Possibility of online orders, Possibility of product modification, Possibility of joint development, Possibility of activities delegation, Possibility of deferred payment. This is one of the most important groups in the evaluation. The answers are formulated in the form of both yes-no answers and the scale of absolute absence through absolute presence of the service.

ES 4-1 Suitability of supplier– final evaluation of the suppliers is done from the viewpoint of total costs, delivery terms and supplier flexibility. The supplier is evaluated on the scale from 0 to 100.

The partial expert systems ES 1-1 to ES 4-1 are integrated in the hierarchic structure outlined in Fig. 4. Their relations result from the logical sequence of the need of solution for the specific sub-tasks.

The input/output linguistic variables are defined by an expert. Their overview and expert system classification is noted in Tab. II.

1.3.3 Supplier Flexibility (ES 3-4) Expert System

The ES 3-4 expert module contains several indicators of supplier flexibility, including the possibility of online ordering and the possibility of final product customisation to the wish of the customer. The word values of the output for the possibility of online ordering are YES (1) or NO (0). The language values for product modification are Insufficient, Sufficient, Average, High and Very High.

For example, the selected two-dimensional functional dependence of the output variable Supplier Quality on two input variables Possibility of activities delegation and Possibility of deferred payment (linguistically expressed in the form of the rule-based model ES3_4 FLD) is numerically represented as the area in Fig. 5.

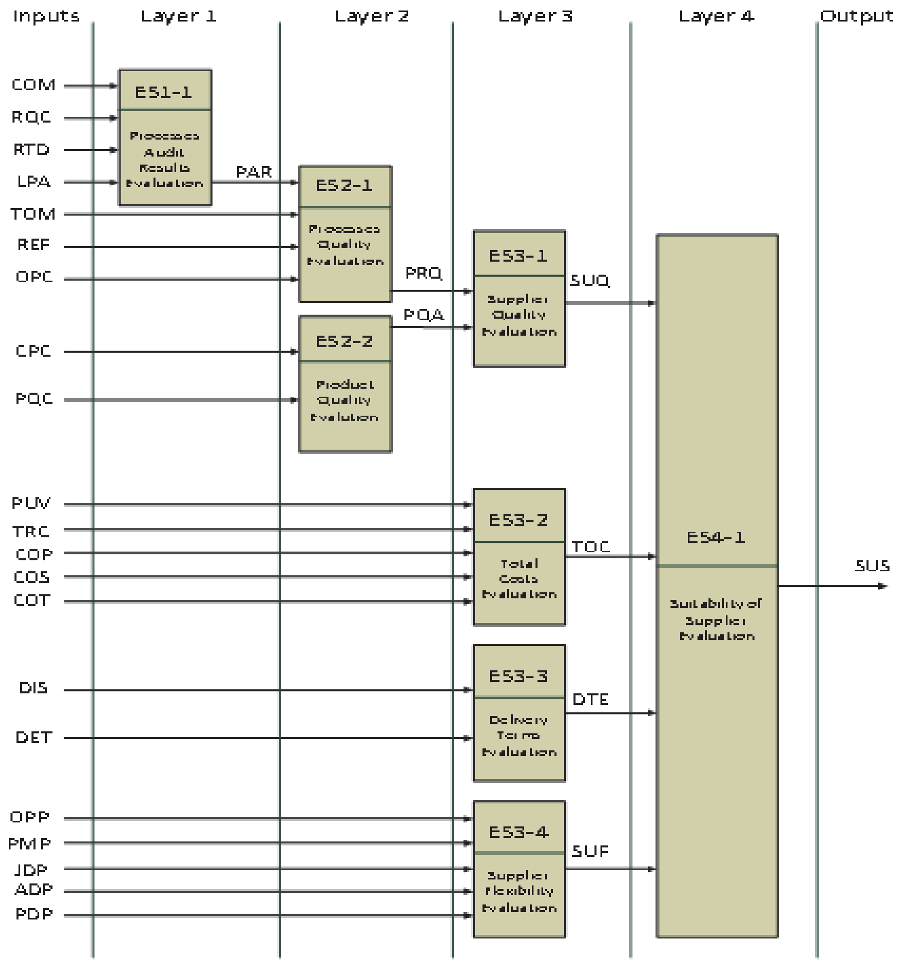
The process of the deduction of concrete input data (approximative deduction), makes use of the principles of language fuzzy logic (Novák, Perfiflieva, Močkoř, 1999). Also the multivalue fuzzy logic which expresses verity values using language evaluation is called language logic. And yet the interpretation of the particular verity values is vague. The outcome of the expert system is the language value of the output variable in the form of a fuzzy set which is converted into the numerical level via the procedure of defuzzification.

The advantage of the language rule models is also their open structure which can be updated with new rules (new knowledge) at any time.

RESULTS

1 Simulation of New and Current Suppliers

The partial expert systems ES 1-1 to ES 4-1 were implemented in the software development environment Fuzzy ToolBox of the MATLAB program package. Their simulation hierarchical



4: *Structure of the hierarchical expert system (source – own)*
Source: our own processing

structure was created in the Simulink (MATLAB) environment.

A common comparison of new and current suppliers is an important part in the current age. The crucial issue is the simultaneous comparison of factual and estimated values – such as service quality, own experience with the supplier, etc. The new method therefore makes use of the comparison of factually researched values of the current suppliers with the estimated average values of the new ones.

The functionality of the system is shown on the example of four suppliers – two current and two new ones. Supplier 1 is a large local producer. Supplier 2 is a large foreign producer. Supplier 3 is a large distributor. Supplier 4 is a small distributor. The results of the simulation inference of the supplier suitability are shown in Tab. III. The outcome of each partial expert module ES 1-1 through ES 3-4, as well as of the global input ES 4-1 (ESM Expert System Module) is the evaluation of the output variable in the range of 1 (minimum) to 100 (maximum). The table shows the Expert's Estimation (Exp) and theExpert System's Estimation (Sys). For every estimation, the table also shows its absolute (e – Estimation Absolute Error) and percentage (% – Estimation Percentage Error) error.

2 Simulation Result Analysis and Commentary

The correctness and accuracy of the expert system function is given especially by the quality of the language models and the quality of their tuning. The exactingof the tuning is dependent on the quality of the expert and the collaborating knowledge engineer. One of the important factors is also the complexity of the decision-making task, represented by the complexity (the number of rules) of its language model.

The correctness of the function of the expert system is evaluated by the absolute difference between the expert's estimation and the expert system's estimation. The level of the presented system shows the absolute error of the specific modules in the range of 0–27%. The worst accuracy of 27% is shown in one out of four inferences of the system ES 2-1, and yet in all three other cases, the error is zero. This situation is typical for the request of fine tuning of its language model. The other cases show the margin of error of 0–13%. The same margin

II: *Expert System Linguistic input/output variables*

Name of variable	IDENT
Communication	COM
Results of quality control	RQC
Rate of technological development	RTD
Clean production application	LPA
Processes audit results	**VAP**
References	REF
Time of market	OPC
Processes quality	**KPC**
Compulsory product certification	CPC
Results of processes quality control	PQC
Product quality	**PRQ**
Quality	**PQA**
Purchasing value	PUV
Transport costs	TRC
Costs of packaging	COP
Costs of storage	COS
Costs tariff	COT
Total costs	**TOC**
Distance to supplier	DIS
Delivery time	DET
Delivery terms	**DTE**
Possibility of online orders	OPP
Possibility of product modification	PMP
Possibility of joint development	JDP
Possibility of activities delegation	ADP
Possibility of deferred payment	PDP
Supplier flexibility	**SUF**
Sustainability of supplier	**SUS**

Source: our own processing

of error was shown by the resulting inference of ES 4–1. Its mean absolute error is 8.7%. It can be said, that according to the practical experience from the field of knowledge engineering, an estimation error of up to 10% is acceptable. In this respect the system is ready to be practically used.

DISCUSSION

The user has to correctly understand the meaning of ES input linguistic variables and has to correctly specify the input values. The sufficiency of input information is the main condition for suitability of using the model. The solution is suitable for the goal of supplier comprehensive assessment.

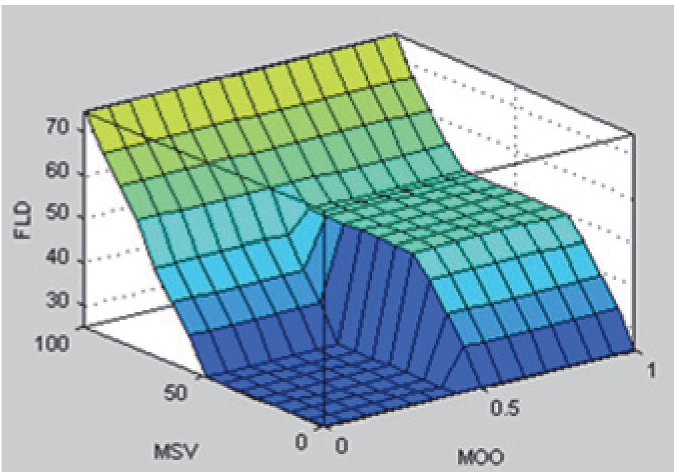
Output information of ES can be used for long term strategic decisions about partnerships and for ordinary supplier evaluation. Model can serve on strategic level for comprehensive assessment of suppliers for future cooperation. Model may be useful in the current assessment as auxiliary performance indicator in various criteria.

The advantage of this solution is the simplicity and transparency of its application with the possibility of combination of various viewpoints on the potential suppliers. The main limitation is the current evaluation of new suppliers with limited input data (estimation by average).

On the basis of the undertaken analysis, it can be said that the new method is operable. The direction for further research can be the addition of further, e.g. environmental, criteria to the new supplier evaluation model.

The synthesis of expert systems is a special problem of knowledge engineering. The technology of expert systems is used also in the task of supplier choice within the framework of the supplier chain.

The structure of the suggested and presented decision-making expert system mirrors the original approach of the authors. Eight fragmentary expert modules, solving fragmentary decision-making tasks, are integrated into the hierarchic structure of the global expert system. The language models of the decision-making tasks are implemented in the Fuzzy ToolBox environment of the MATLAB-



5: *Input/output dependency FLD = f(MSV, MOO)*
Source: our own processing

III: *Simulation experiments results*

SUPPLIER 1 Large Local Producer					SUPPLIER 2 Large Foreign Producer					SUPPLIER 3 Large Distributor					SUPPLIER 4 Small Distributor				
ESM	**Exp**	**Syst**	**e**	**%**	**ESM**	**Exp**	**Sys**	**e**	**%**	**ESM**	**Exp**	**Syst**	**e**	**%**	**ESM**	**Exp**	**Syst**	**e**	**%**
ES 1-1	65–75	73	0	0	ES 1-1	65–70	79	9	13	ES 1-1	65–75	68	0	0	ES 1-1	65–70	78	8	11
ES 2-1	50–60	50	0	0	ES 2-1	20–25	23	0	0	ES 2-1	20–30	20	0	0	ES 2-1	10–15	19	4	27
ES 2-2	80	75	5	6	ES 2–2	55	53	2	4	ES 2-2	80	75	5	6	ES 2-2	50–55	53	0	0
ES 3-1	65–70	75	5	7	ES 3-1	30–35	28	2	7	ES 3-1	20–30	24	0	0	ES 3-1	5–10	9	0	0
ES 3-2	25–35	31	0	0	ES 3-2	45–55	42	3	7	ES 3-2	65–75	60	5	8	ES 3-2	65–75	59	6	9
ES 3-3	80–90	91	1	1	ES 3-3	25–30	33	3	10	ES 3-3	65–70	74	4	6	ES 3-3	65–75	76	1	1
ES 3-4	65–75	75	0	0	ES 3-4	45–55	60	5	9	ES 3-4	10–15	8	2	13	ES 3-4	10–15	8	2	13
ES 4-1	**85–95**	**90**	**0**	**0**	**ES 4-1**	**50–55**	**60**	**5**	**9**	**ES 4-1**	**25–30**	**34**	**4**	**13**	**ES 4-1**	**25–30**	**34**	**4**	**13**

Simulink system. An important feature of the language modes is their open structure which can at any time be complemented with new rules (new knowledge).

The function of the expert systems was verified by simulation experiments. These experiments focused on the examination of two current and two new suppliers. The accuracy of function was then analysed and commented on. The difference between the estimation of the expert and the system is on a level corresponding to the technology of the solution used.

In many cases, the results ES may be distorted or model cannot be used. Model doesn't work properly in the case of some input data absence (doesn't apply to the anticipated data about new suppliers).

If the dominant role in decision making play the factors that are not included in the ES (political situation, environmental policy, the subjective preference of management), then the simulation result and the view of "live expert" can greatly vary.

Fuzzy logic rule-based model, from which ES deduces output information to the user, has open structure. If needed include to the decision making process the other aspects (input variables), it is possible to extend the model with new expert-defined rules.

CONCLUSION

The main goal of this paper is an analysis of the decision-making task of the choice of the supplier, leading to a definition of its partial subtasks and a suggestion of a corresponding language model expert system. The partial goals of the paper are the presentation of the current trends in the area od expert system use for the supplier choice, presentation of the principles and processes of synthesis of the fuzzy oriented expert systems for the solution of fragmentary subtasks, the integration of a global hierarchic expert system, simulation confirmation of the system function on the example of the task of choice from two current and two new suppliers and finally an analysis and outlook onto the direction of further research. The structure of the suggested and presented decision-making expert system mirrors the original approach of the authors. Eight fragmentary expert modules, solving fragmentary decision-making tasks, are integrated into the hierarchic structure of the global expert system. The language models of the decision-making tasks are implemented in the Fuzzy ToolBox environment of the MATLAB-Simulink system. An important feature of the language modes is their open structure which can at any time be complemented with new rules (new knowledge). The function of the expert systems was verified by simulation experiments. These experiments focused on the examination of two current and two new suppliers. The accuracy of function was then analysed and commented on. The difference between the estimation of the expert and the system is on a level corresponding to the technology of the solution used.

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