Developing Expert Systems in Decision Making by Applying the Fuzzy Set Theory

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Abstract: - The main goal of this paper was to present the knowledge based fuzzy model that will provide more successful and efficient decision making in the area of marketing, in relation with dilemma “to produce or to buy”. Namely, authors tried to develop a model that will be suitable for making marketing decisions in production systems. Methodology in the paper obtained analysis of the theory of marketing and knowledge based systems, the development of the specific model for decision making, so as the application of developed model on one case from domestic production system. The research problem in this paper was proposed in terms of model development. Authors developed model for decision making, based on successful integration of marketing and knowledge based and fuzzy theories. Also, this was proposed as universal model which can be implemented in each production system. They implemented the model in decision making problem related to the debate “to produce or to buy” on one real decision problem in domestic production system. The paper was divided in three parts. In the first part authors analyzed the main theoretical developments in the area of marketing and decision making, fuzzy and knowledge based systems. The second part was dedicated to the methodology and thus the development of the model for marketing decision making. The third part presented the model and specific decision making problem that has been solved by developed model. At the end, authors pointed the advantages of the model but also some limitations and possibilities for the future researches.

Key-Words: - knowledge-based systems, fuzzy logic, decision making process, uncertainty

1 Introduction

In order to expound on the application of the fuzzy set theory in marketing decision making properly, it is necessary to start from the essence of marketing decision making. Marketing decision making is an integral part of marketing management, which is, in a sense, the art and science of applying core marketing concepts to choose target markets and get, keep, and grow customers through creating, delivering, and communicating superior customer value [13].

Marketing decision makers include marketers, marketing managers, buyers, shopping centres, influential individuals, users, analysts, and also formal or informal authorities featuring in the process of choosing marketing alternatives. They feature both on the supply and demand side, given that a social and managerial process by which individuals and groups obtain what they need and want through creating and exchanging products and values with others [12]. Besides, marketing decision making process is more often analysed from the supply aspect in professional literature, covering decision making on global or local marketing engagement, choice of target markets, methods of entering target markets, combining marketing mix elements and implementing, i.e. controlling marketing activities.

Marketing decisions in modern-day business are made under conditions of growing uncertainty, which cannot be measured, and business risks, which are measurable. High uncertainty and risk levels result from disruptive innovations and great unexpected shocks [14]. Marketing decisions have always been made under the conditions of uncertainty and risk, but modern-day pace of change and intensity of shock are more extreme than ever. For this reason, market decision makers should be qualified for appropriate assessment of acceptable risk level, so as to secure the best effects and control the damage from made marketing decision. Applying the fuzzy set theory is a good example of such approach to marketing decision making.

In most cases, marketing decisions are made under conditions of uncertainty and high risk.
According to some authors [15]; [26], this is most contributed to by:

- a relatively high number of relevant variables;
- impossibility of controlling relevant variables;
- their instability and nonlinearity, stochasticity of relevant variables;
- difficult quantification and measurement of effects of relevant variables;
- shortage of marketing information.

The decision maker’s expertise and appropriate assessment of tolerable risk levels (i.e. the subjective factor) is therefore of extreme importance for the final effects of decision made.

The main goal of this paper was to present the knowledge based fuzzy model that will provide more successful and efficient decision making in the area of marketing, in relation with dilemma “to produce or to buy”, because the make-or-buy methodology is one of the most critical strategic decisions within logistics outsourcing and should be taken in a structured and consistent manner [2]; [4]. Namely, authors tried to develop a model that will be suitable for making marketing decisions in production systems. Methodology in the paper obtained analysis of the theory of marketing and knowledge based systems, the development of the specific model for decision making, so as the application of developed model on one case from domestic production system. The research problem in this paper was proposed in terms of model development. Authors developed model for decision making, based on successful integration of marketing and knowledge based and fuzzy theories. Also, this was proposed as universal model which can be implemented in each production system. They implemented the model in decision making problem related to the debate “to produce or to buy” on one real decision problem in domestic production system.

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2 Problem Formulation

Making marketing decisions is aimed in two basic directions, i.e. towards solving problems on the one hand and using the benefits of business opportunities on the other. At any rate, marketing decision making enables a transition from the current state into a new, i.e. desired state, which marketing decision makers deem to be more favourable for the company.

The well-known opinion is that different problems “call” for different types of decision making. To a great extent, types of marketing decisions also determine methods applied in making those decisions. Furthermore, marketing decision makers must be qualified for precise problem definition, primarily in terms of certainty or uncertainty of its outcome.

Theoretically, marketing decision making process is structured differently, but the key phases of this process that can be singled out are the diagnostic phase or problem identification, action plan which implies defining the alternative avenues of undertaking marketing activities and choosing marketing alternatives, and also implementation, including marketing control and revision. Marketing theory displays a great similarity of the decision making process to the problem solving process, which has even led some authors to equate their meaning.

When viewing the areas of decision making in marketing, decision making in the business community and practice is often related to the issues of creating an optimum marketing program, i.e. making decisions on the product, developing and launching a new product, pricing, marketing channels and marketing communication. In all instances of marketing decision making, companies that apply marketing orientation in business operations produce effects manifested in the operation of all business functions.

The classical decision making operates with a set of alternatives over the space of decision, a set of states off affairs over the space of the state of affairs, relation pointing to states or outcomes expected from each of the alternative actions, and finally, the utility or the goal function, which arranges these outcomes in accordance with the desired outcome. Decision making is said to be performed under conditions of certainty, when the outcomes of any action can be precisely determined and arranged. In such cases, alternatives are chosen that lead to outcomes with maximum utility. On the other hand, a decision is made under conditions of risk, when the only knowledge available regarding
the state of outcomes is their probability distribution.

In any real-life situation, including the decision making and management fields – whether it is about setting goals and formulating strategies, or selecting, implementing and monitoring the selected strategy – many processes are unfit for mathematical modelling. In normal real-life situations in various areas of human activity, very often we do not know the equations for most non-linear processes and systems and therefore resort to approximation. Fuzzy systems approximate those equations. Fuzzy systems enable us to make optimum approximations of the non-linear universe. If it is possible to build a mathematical model, we shall use it. There is always a question: how can we know that mathematical approximation corresponds to a process in reality? Fuzzy systems enable us to model the universe in linguistic terms, rather than forcing us to write a mathematical model of the universe. The technical term for it is model-free function approximation [26]. Here is important to emphasize that for many knowledge-intensive applications, it is important to develop an environment that permits flexible modelling and fuzzy querying of complex data and knowledge including uncertainty [16].

A very common problem encountered by marketing decision makers in companies, also related to production, finance and purchase, is the dilemma whether a certain product, part or semi-manufactured product should be produced by engaging their own resources, at their own plants, or obtained from suppliers. This problem requires coordinated approach to solving, and can manifest itself in practice in three forms:

- produce or purchase a product previously not used by the company;
- independently produce the product previously purchased from suppliers or
- purchase the product currently produced by engaging their own resources at their own plants.

The “make-or-buy decision” is about the choice of weather to carry out a particular process or activity within a business or to buy it in from a supplier. In recent decades, the “make-or-buy decision” shifted from the level of reactive clerical function to the center of business strategy. It was realized that sourcing decision have a great effect on business strategy and that sourcing decision has a great effect on a business future survival. The make or buy decision can often be a major determinant of profitability making a significant contribution to the financial health of the company [19]. This dilemma was explored in past years in different systems, from food production sector [25]; [24], pharmaceutical production [33], bicycle derailleur and freewheel production [23], temporary agency work [1], etc. Solving this problem demands meticulous approach and engaging experts of various profiles, where the marketing expert figures as the coordinator of all activities.

Resolving the given problem can be approached along three avenues:

(a) by the classical method;
(b) by applying the expert system and
(c) by applying the fuzzy set theory.

The classical method is usually related to the transaction costs. The transaction cost theory of the firm introduced by [7] has been made a standard framework for the study of institutional arrangements by [30]; [31]. The Coasian framework helps explain not only the existence of the firm, but also its size and scope. Some firms are highly integrated. Others are much more specialized. Why do some firms choose a vertically integrated structure, while others specialize in one stage of production and outsource the remaining stages to other firms? In other words, should firm make its own inputs, should it buy them on the spot market, or should in maintain an ongoing relationship with a particular supplier? Traditionally, economists viewed vertical integration or vertical control as an attempt to earn monopoly rents by gaining control of input markets or distribution channels. The transaction cost approach, by contrast, emphasizes that vertical coordination can be an efficient means of protecting relationship – specific investments or mitigating other potential conflicts under incomplete contracting. As transaction cost economics was developed in the 1970’s and 1980’s, a stream of empirical literature emerged explaining the “make-or-buy decision” using transaction cost reasoning, where the influence of transaction costs on decisions to make or buy components was assessed indirectly through the effects of supplier market competition and two types of uncertainty, volume and technological [29].

The traditional dichotomous make and buy sourcing strategies have been established in the transaction cost economics (TCE) literature [23]. The basic characteristic of the classical approach to resolving a business dilemma is almost exclusive reliance on comparing the economic effects of both decisions. In other words, the total costs related to producing the given part/subset/product are compared with the total cost of purchasing the same item (provided that that there are suppliers where the given part/subset/product can be purchased), and then the decision maker opts for the more cost-
effective option. Only in rare cases (depending on the decision maker’s expertise) are additional criteria taken into account as well [27].

Outsourcing is purchasing from someone else a product or service that have been previously manufactured internally. It is becoming an increasingly important element in strategic decision-making and an important way to increase efficiency and often quality. The sourcing decision can cover a wide range of goods and services ranging from manufactured components, semi-processed materials [8] and constancy services. The outcome of these decisions is influenced by a considerable number of factors and the soundness of assumptions. Traditionally, cost had been viewed as the main consideration in sourcing decision [26]; [17]. Also, one more factor which is important in the process of sourcing decision making is the level of technology development. For example, on the basis of 1990–2002 panel data set on Spanish companies and an exogenous proxy for technological change it have been provided thee causal evidence that technological change increases the likelihood of outsourcing [3].

Almost unknown to the academic world, and to the general public, the application of intelligent knowledge-based systems is rapidly and effectively changing the future of the human species. Today, human well-being is, as it has been for all of history, fundamentally limited by the size of the world economic product. Thus, if human economic well-being (which I personally define as the bottom centile annual per capita income) is ever soon to reach an acceptable level (e.g., the equivalent of $20,000 per capita per annum in 2004), then intelligent knowledge-based systems must be employed in vast quantities. This is primarily because of the reality that few humans live in efficient societies (such as the United States, Canada, Japan, the UK, France, and Germany, for example) and that inefficient societies, many of which are already large, and growing larger, may require many decades to become efficient. In the meantime, billions of people will continue to suffer economic impoverishment—an impoverishment that inefficient human labour cannot remedy. To create the extra economic output so urgently needed, we have only one choice: to employ intelligent knowledge-based systems in great numbers, which will produce economic output prodigiously, but will consume hardly at all. According [20] “the creation and development of the knowledge based society and knowledge economy are perceived as one of the most important priorities of the modern society and its lifestyle development, as well as of social, economic, political development, science and technological progress”.

Since the make or buy decision is presented in wide range of researches in the world, there have been made several attempts for creation the framework for “make or buy” decision making process [6]; [9]; [5]. Based on these researches authors proposed the methodology for development of one knowledge based framework for decision making in the mentioned area. Fig. 1 (Appendix 1)

### 3 Problem Solution

It is due to the importance of additional criteria that a prototype of the expert system was developed (including software solutions). As the economic model in Fig. 2 (Appendix 2) shows, the number of attributes taken into account is far greater compared to the classical decision making method.

The decision maker communicates with the expert system by choosing the domains of values for the attribute of the decision making leaf nodes. Using the built-in logarithm, the expert system proposes a solution with explanation based on these data. The risk of making a wrong decision is thus multiply reduced, which was the basic objective of developing the expert system [10].

Fuzzy systems enable us to make optimum approximations of the non-linear universe. If it is possible to build a mathematical model, we shall use it. Fuzzy systems enable us to model the universe in linguistic terms, rather than forcing us to write a mathematical model of the universe. The technical term for it is model-free function approximation.

The Fuzzy Approximation Theorem claims that a graph can always be covered with a finite number of fuzzy patches. The more uncertain the rule, the larger the fuzzy patch. According to the Fuzzy Approximation Theorem, a fuzzy system can approximate a continuous system to a sufficient degree of accuracy. This includes almost all systems studied by science. Fuzzy systems can model dynamic systems changing over time [22].

Viewed geometrically, every portion of human knowledge. A fuzzy system is a large set of fuzzy “if … then” rules, representing “a large set of patches”. The more knowledge, the more rules. The more rules, the more sets. If the rules are more indefinite, i.e. uncertain, the patches are larger. If the rules are more definite, the patches are smaller. If the rules are so precise that they are not fuzzy, then patches are reduced to points.

The Fuzzy Approximation Theorem says more than that. Theoretically, all equations can be translated into rule patches. Fuzzy systems
approximate systems in physics, communication, physiology, etc. Fuzzy systems can be applied wherever the brain is used.

It is hard to deny that modern-day knowledge is fuzzy. Meanings of statements are undoubtedly fuzzy. Knowledge has always been regarded in terms of rules. If knowledge is fuzzy, then rules are fuzzy as well. Fuzzy rules connect fuzzy sets. Fuzzy patches cover the system graph. It is the Fuzzy Approximation Theorem and fuzzy patches that explain the functioning of fuzzy systems.

A solution to the given problem by applying fuzzy set theory, the economic model (Fig. 2; Appendix 2) can be supplemented with an oriented graph. Input variables occur at the first and second levels. The second level already contains four functions of two arguments; the third level also contains two functions of two arguments, but some of the arguments at the previous are level defined functions, i.e. complex functions. The fourth level is a function of two arguments defined at the third level, i.e. the obtained function at the fourth level is multiply complex, and its value is the solution to the problem. (If required, this model can be extended to more or reduced to fewer levels.) However, these are not functions and their arguments in the classical mathematical sense. The input variables (arguments) are linguistic variables ("high raw material costs", "medium quantity of product", "aggressive suppliers' approach", "status quo in the forthcoming 3-5 years, but development over the subsequent ten plus years", etc. The same applies to output variables (functions), representing input functions for complex functions up to the last level, such as production costs, purchase price, foreseen technological change, production limitations etc. Such nature of input and output variables, i.e. value domains that cannot be accurately quantified, make the fuzzy set theory extremely convenient for problem solving in marketing decision making.

From a standpoint of computational theory of perception of "computing with words", this method begins by converting the natural perceptions of how usual or unusual the possible states are into probability estimates on a ratio scale, and converting the natural perceptions of how acceptable or unacceptable the possible outcomes of state-action pairs are into utility numbers on an interval scale using Von Neuman-Morgenstern (1947) utility theory or some similar method.

Fuzzy logic is very often successfully applied for modelling problems where interdependences between individual variables are highly complex. This is how resolving the above described problem was approached. Input and output variables were defined as different fuzzy sets, both continuous and discontinuous. Defining fuzzy sets intrinsically implies that the appropriate degree of belonging is ascribed to all possible values, followed by defining inference rules, which mandatorily includes the operation of logical implication with input conjunction and/or disjunction. Having determined the degree of belonging, values of output variables, with minimum but certain and guaranteed degrees of belonging, are chosen for every rule, considering all the input variables. After this, the observed output variable is still not unequivocally defined, for it has different values with different degrees of belonging at all points, depending on the number of used rules. The next step is choosing the output variable values with maximum degrees of belonging. An output variable is thus obtained and subsequently defuzzified, i.e. a specific numeric value is determined, which is either the input variable on the next, higher level, or the decision, i.e. solution to the problem, on the last level. Thus, the final decision is made by using multiple steps, taking into account all possible circumstances and all the possible variable values occurring in it. Such complete consideration and problem analysis would be impossible to do without fuzzy logic, relying only on experts’ knowledge, experience and intuition.

The following is the overview of fuzzy variables with possible value domains:

- **DECISION:** produce, purchase;
- **PRODUCTION LIMITATIONS:** enormous, substantial, negligible, none;
- **ECONOMIC EFFECTS:** significant, favourable, unfavourable, devastating;
- **EXTERNAL FACTORS:** favourable, neutral, unfavourable;
- **EXPERTISE:** high, average, low;
- **CAPACITY UTILISATION:** high, average, low;
- **PRODUCTION COSTS:** high, average, low;
- **PURCHASE PRICE:** high, moderate, low;
- **TECHNOLOGICAL CHANGES:** confining, tolerable, negligible;
- **SUPPLIERS’ APPROACH:** aggressive, moderate, passive;
- **QUANTITY OF PRODUCT:** large, medium, small;
- **PRODUCTION SCHEDULE:** weekly, monthly, quarterly, semi-annual;
- **RAW MATERIAL COSTS:** high, moderate, low;
- **LABOUR COSTS:** high, moderate, low;
- **SUPPLIER RELATIONS:** excellent, good, poor;
- **TRANSPORT COSTS:** high, moderate, low;
- **LONG-TERM CHANGE:** development, status quo, elimination;
- **MID-TERM CHANGE:** development, status quo, elimination.
According to their belonging functions, the above fuzzy variables in the observed problem can be observed as follows:

- **Group I:** raw material costs, labour costs, production costs, transport costs, purchase price, quantity of product, capacity utilisation, external factors (Fig. 3). The value interval (a,b) is determined in each specific case. The observed variables are measured in monetary units, excluding capacity utilisation, foreseen technological change and external factors expressed in percentage.

![Fig. 3 Group I](image)

Table 1

<table>
<thead>
<tr>
<th>EXPERTISE A</th>
<th>CAPACITY UTILISATION</th>
<th>PRODUCTION LIMITATIONS</th>
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<tr>
<td>high</td>
<td>high</td>
<td>none</td>
</tr>
<tr>
<td>high</td>
<td>average</td>
<td>negligible</td>
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<tr>
<td>average</td>
<td>high</td>
<td>substantial</td>
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<tr>
<td>&lt; high</td>
<td>average</td>
<td>negligible</td>
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<tr>
<td>low</td>
<td>high</td>
<td>substantial</td>
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<th>ECONOMIC EFFECTS</th>
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<td>unfavourable</td>
</tr>
<tr>
<td>high</td>
<td>&lt;high</td>
<td>devastating</td>
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<tr>
<td>average</td>
<td>high</td>
<td>favourable</td>
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<tr>
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<td>low</td>
<td>substantial</td>
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<tr>
<td>low</td>
<td>moderate</td>
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<tr>
<td>low</td>
<td>low</td>
<td>unfavourable</td>
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<tr>
<th>TECHNOLOGICAL CHANGES A</th>
<th>SUPPLIERS’ APPROACH =&gt;</th>
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<td>unfavourable</td>
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<td>passive</td>
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Step 3

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<tr>
<td>enormous</td>
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<td>enormous</td>
<td>&lt;significant</td>
<td>purchase</td>
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<tr>
<td>substantial</td>
<td>significant</td>
<td>unfavourable</td>
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<tr>
<td>substantial</td>
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<td>devasting</td>
<td>* purchase</td>
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<tr>
<td>none</td>
<td>&gt;unfavourable</td>
<td>* unfavourable</td>
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The asterisk (*) marks that the attribute can take on any value from the domain in this rule.

- **Group II:** long term change, mid-term change (Fig. 4). The measurement unit is the degree of expected change.

- **Group III:** production schedule (Fig. 5). The measurement unit is time expressed in months.

![Fig. 4 Group II](image)
Group IV: relations with suppliers, suppliers’ strategy (Fig. 6). The measurement unit is assessment grade for suppliers.

Group V: expertise (Fig. 7). Presence of higher qualification is expressed in percentage.

Group VI: production limitations, economic effects (Fig. 8); measured in percentage, from the “produce” aspect.

Group VII: decision (Fig. 9); expressed in percentage, from the “produce” aspect.
The approximate reasoning algorithm for making the business decision whether to produce or purchase consists of three basic steps. Each basic step is divided into several interconnected steps. Each of these substeps, or steps, contains a logical inference rule defined by experts. As specified numeric values directly entered at the given moment of making the “purchase or produce” decision, the input data are as follows: expertise, quantity of product, production schedule, raw material costs, labour costs, supplier relations, transport costs, and long- and mid-term changes. As illustrated in Figures 3-9 above, fuzzy sets are already prepared at all levels. Direct entry of the above listed first- and second-level data activated the above defined algorithm. The algorithm is illustrated in graph 1(b) of Fig. 10. Production costs are defuzzified by determining the centre of gravity using the known formula. Thus obtained numerical data is the input value for step 2(b).

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4 Conclusion
This article has developed a heuristic diagram for making the “purchase or produce” business decision. The problem per se has all the characteristics of uncertainty. A serious problem, therefore, is determining input variables and forecasting all possible circumstances, which is only possible based on subjective estimate. An estimate with a degree of accuracy is much easier to obtain for a range of data than for an individual value.

Fuzzy sets can be introduced into the existing decision making models in several ways. As an economic institution, a company bases its existence on the environment, both from the aspect of providing input and from the aspect of achieving and valorising input. Miscellaneous knowledge and experience, and also decision making in the areas of investment, market operations, financial function, production function or research and development, can be considered more fully and exactly applying fuzzy sets.

The fuzzy set theory provides a solution to this. Individual steps of the algorithm are based on fuzzy logic rules. The algorithm was verified on multiple numeric examples, and development of an appropriate software product is in progress. The essential feature of this algorithm is that there is no possibility of “setting up” a desirable decision by tailoring input data.

References:


Appendix 1

Fig. 1 Framework for Make or Buy decision making
Source: [5] p.1322

Appendix 2

Fig. 2 Decision tree for problem solving: "Produce or purchase"