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FUZZY HODNOCENÍ INVESTIC – BROWNFIELD REDEVELOPMENT

FUZZY INVESTMENT DECISION SUPPORT
FOR BROWNFIELD REDEVELOPMENT

Zkrácená verze Ph.D. Thesis

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KEY WORDS

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INTRODUCTION

This research focuses on several areas including investing, decision making and brownfield redevelopment. Decision makers often have a very difficult task because they have to analyze large amount of information and they have a very limited time to make the decision. Long-term investments like for example the purchase of new building complex or a brownfield site have strategic importance. These investments require a significant amount of resources and incorrect decisions are costly.

As the amount of available information is steadily increasing there is a need to develop new sophisticated methods that facilitate the process or data collection, analysis and evaluation. There is a significant difference between different fields of science. For example mathematics and physics have precise variables and relations. Social sciences like for example economics have also variables and relations but it is more difficult to measure and evaluate these variables. Physics has general laws and rules that are constant and valid at all times. Economics also has laws but the market environment is constantly changing. It is more difficult to make predictions about the future markets than it is to predict the behavior of a system which follows the precise rules of physics. Fuzzy logic allows researchers to work with imprecise or even unknown variables that can frequently be found in economics or in investment decisions.

This dissertation discusses the use of fuzzy logic and modeling and its application in investing. This research focuses on the application of fuzzy logic as a decision making support for investors who plan to redevelop a brownfield site. Due to a high degree of complexity of this decision making problem - the goal of this research is to design a complex method that facilitates the use of fuzzy logic in economics and especially in the field of real estate investment and in the process of investment evaluation of brownfield sites.

1 RESEARCH OBJECTIVES

This chapter discusses the individual research objectives. Due to the complex nature of the decision making process about long-term investments it is necessary to reach several objectives at once. All these objectives are important in different phases of the research. This research is conducted with the intention to create a reliable method that can be applied to solve real problems in the real market environment. The proposed method has to be composed of well defined elements and relations between these elements to ensure that investors who will apply this method to help them solve their problems are satisfied with the recommendations this method will produce for them.

Primary objective of this research:

To develop a complex decision support method that will process the input data (supplied or collected) and reduce the large set of possible decisions to a significantly smaller set of alternative decisions based on the hierarchy and precise definition of the relevant criteria, requirements and objectives that are used for the evaluation of the supplied input data.

Secondary objectives of this research:

To develop support software for the proposed method. For example applications that will allow to efficiently collect relevant information from internet databases of real estates and automatically process this information. To develop software application that will transform the input data and information about the relevant criteria into a fuzzy model that can be used by the chosen fuzzy logic software. Additional software is required to process the large amount of information that the fuzzy model outputs so that the evaluation of the resulting information is efficient.

To collect information about brownfield sites, generate a complex test fuzzy model and thoroughly test different scenarios with different sets of relevant criteria and conditions so the model is robust. Researched method has to be robust and reliable enough so it meets the needs of real decision makers and investors.

2 THEORETICAL FOUNDATIONS OF THIS RESEARCH

This chapter contains information about the scientific methods used in this research, related research and theoretical foundations of this research. To develop a complex system that helps decision makers to decide about purchase of a real estate requires input from several other research areas. This research is closely related to optimization, modeling, graph theory, soft computing, data mining, investing, multiple criteria decision analysis, fuzzy logic and other fields. Relation between these areas and the research problem is discussed in greater detail in dissertation.

2.1 SCIENTIFIC METHODS USED IN THIS RESEARCH

Before the individual research methods are discussed it is required to define the term method. Method is understood as a body of techniques for investigating phenomena, acquiring new knowledge or correcting and integrating previous knowledge. Methods are usually formulated like a set of special rules which have to be followed in order to achieve the desired results. In science a method has to be based on gathering observable, measurable and empirical evidence. Methodology is a theory about methods of scientific inquiry. Methodology can be also described as the systematic study of methods that are, can be or have been applied within a discipline or just as the study or description of methods. These individual scientific methods are used in this research:

- Abstraction and concretization - abstraction is a process in which the essence and character of a certain object is being identified. On the other hand concretization is the method of finding concrete elements from a group of objects.
- Induction and deduction - deduction, deductive reasoning or deductive logic is a type of reasoning which constructs or evaluates deductive arguments. Induction also known as inductive logic or educated guess is a kind of reasoning that draws generalized conclusions from a finite collection of specific observations.
- Modeling and simulation - modeling is a process of generating abstract, conceptual, graphical or mathematical models. A scientific model can provide easier way to understand a complex system because the elements in the model are simplified and the important relations between the elements are clearly observable. Simulation is the implementation of the model.

- Feedback - feedback method is used to closely observe the changing results caused by changes in the input data or by changes in the model. It allows to evaluate the impact of individual changes.
- Heuristic methods - heuristics refers to the experience-based techniques for problem solving, learning and discovery. Heuristics are strategies using accessible information to control problem solving done either by humans or machines. Heuristic method is frequently used to identify an optimal solution as fast as possible. Comparison can be defined as a process of examining resemblance or finding common traits and characteristics.
- Analysis and synthesis - analysis is a process of dividing a complex topic, substance or system into smaller parts to gain a better understanding of it. Synthesis refers to a combination of two or more entities that together form a new complex entity. Synthesis can be also defined as the formation of something complex or coherent by combining simple elements.

2.2 LITERATURE REVIEW AND RELATED RESEARCH

Following chapters discuss important details found during the literature review phase. This chapter contains a list of scientific papers related to the application of fuzzy logic in economics, real estate investment and application of soft computing in economics. Extensive search for research papers focused on the application of fuzzy logic in the area of brownfield redevelopment was conducted and most research papers found used fuzzy logic in other areas such as logistics, forecasting, stock trading etc. Only one paper was found which directly relates the use of fuzzy logic with brownfield redevelopment. Fuzzy logic is suitable for the use in economics particularly because of its ability to work with models containing unknown or imprecise information. Fuzzy logic is used often to work with the dynamics of stock exchange by other researchers. It is also used for the predictions about the future development of chosen variables and to examine the complex dependencies between economic variables. Two colleagues from the Faculty of business and management also lead by my research adviser prof. Dohnal successfully applied fuzzy logic in economics. These two dissertations are listed below. One research paper related to brownfield redevelopment and utilization of fuzzy logic for decision making support was published in 2009. This research paper discusses the use of fuzzy real options instead of the traditional net present value method which is used currently by most investors. Even though NPV method has a list of disadvantages, it is easy enough for most investors to calculate themselves.

This research proposes a more complex method which uses more information about the investment alternatives and outputs complex information about the individual brownfield sites and the measure of their similarity to other brownfields. Even after an extensive search for similar application of fuzzy logic - no research paper which uses a model similar to a model proposed in this research or a hierarchy of variables which is used in this research was found. The objective of this research is not only to produce a theoretical proof that this approach is viable, but also to offer the newly researched method as a service to real investors. This new decision support method is offered as a service and not as a single application because the process is too complex and once programmed it would no longer offer the required flexibility.

2.3 CONDITIONS INFLUENCING THIS RESEARCH

This research is influenced by several conditions. Market environment in Czech Republic is evolving and there are many possibilities for investors who have free resources. The prices of real estate are steadily increasing and it is possible to expect that they will be comparable to prices in other European countries.

Currently the investor often does not have a sophisticated software available which would simplify the decision making process about the ideal investment alternative. Classical approaches like for example MCDA or financial indicators are used in order to find the ideal investment alternative. The process of data collection and analysis is often slow and requires a lot of manual work and time. This research aims to facilitate and accelerate this process – extract more information from the available data and process it more efficiently. Although the proposed method is complex the time required to perform all necessary processes is relatively short – when considering that a large number of investment alternatives can be analyzed at once the new research has clear advantages over the regular approaches.

Disadvantages of commonly used approaches

- Investors consider only a small set of investment alternatives located close.
- MCDA approach is complex and requires a relatively long time.
- NPV approach is influenced by the estimates made by the investor - that significantly impacts the obtained results.
- The whole process is performed manually. Some investment alternatives are excluded from the process only because it would require too much time to collect and analyze the information about these brownfield sites.
- Individual decision maker does not perform such complex decision making problems related to brownfield redevelopment often unless its employer is a company which focuses on brownfield redevelopment. Therefore most decision makers do not have predefined methods they can use from the past.
- If all the information is processed manually without special software the time required for the whole process is a limiting factor.

This research aims to address these problems and to develop a complex method that will be offered to investors as a service which helps them to find investment alternatives best matching their requirements and objectives efficiently.

2.4 BROWNFIELDS

Brownfields are abandoned or underused industrial and commercial facilities available for re-use. Expansion or redevelopment of such a facility may be complicated by real or perceived environmental contamination (Davis, 2002). This research is partially focused on brownfields and on ecological aspects related to brownfields. It is very important to reuse existing real estates. Due to the changing market environment in Czech Republic in the past two decades there are many capacities that are not used. According to the National strategy for brownfield redevelopment published by Czech Invest there were close to 2300 brownfield sites in the Czech Republic with a total area of 10 300 hectares in 2008. Further information about brownfields in the Czech Republic can be found in (Czech Invest, 2008). These numbers include areas used for agriculture. Out of the 2300 only 176 sites were identified to be contaminated. It is possible to purchase and redevelop these brownfields. However there are specific factors to consider like for example the contamination of soil or investments that have to be made to meet the recent more strict legislation related to ecology. Soil and groundwater under the brownfield may be contaminated by pollution or hazardous waste.

Redevelopment of brownfields is attractive for investors because of a list of benefits which can be divided into - social, economic and other benefits. For example the value/price of surrounding real estate is positively influenced. Local community also welcomes efforts to clean up brownfield sites. Redevelopment brings new jobs as well as the newly opened facility that will emerge from the brownfield site after the revitalization.

2.5 FUZZY LOGIC

Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. Fuzzy logic is derived from the fuzzy sets initially researched by Lotfi A. Zadeh in 1965. In contrast with binary sets having binary logic, also known as crisp logic, the fuzzy logic variables may have a membership value of not only 0 or 1 (Klir & Yuan, 1995). Just as in fuzzy set theory with fuzzy logic the set membership values can range (inclusively) between 0 and 1, in fuzzy logic the degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth values {true (1), false (0)} as in classic propositional logic (Novák et al., 1999).

Fuzzy logic uses linguistic variables and dictionaries of these variables. Work with variables is slightly more complex because of the additional operations required by fuzzy logic. But this additional effort awards the decision maker by answers to questions that cannot be answered by other methods. There are only few conditions that the problem has to meet so fuzzy logic can be used to solve this problem. Human behavior cannot be precisely quantified and so it is easy to work with it with word variables like for example small preference, medium preference, high preference of various products. The membership function can be described graphically by using curves. These curves have shapes similar to the letters "S", "Z", "λ" and "π". The membership functions are applied not only to the input variables but also to the output variables.

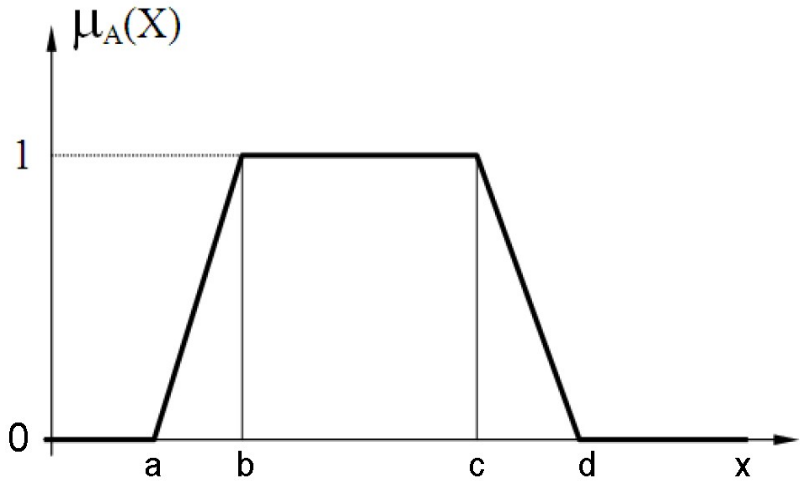


Figure 1: Grade of membership in a fuzzy set (Source: Own work)

There are several different grades of membership determined by points a, b, c and d:

$a = b = c = d$	(precise numeric value)
$a = b$, $b < c$, $c = d$	(interval of uncertainty)
$a < b < c < d$	(trapezoidal fuzzy set)
$a < b = c < d$	(triangular fuzzy set)
$a = b = -\infty$, $c = d = \infty$	(unknown information)

Values outside of the interval (a; d) have a grade of membership equal to zero:

$$\mu_M(-\infty; a) \wedge (d; \infty) = 0$$

Values in the interval (b; c) have a grade of membership equal to one:

$$\mu_M(b; c) = 1$$

Values in intervals (a; b) and (c; d) belong to the fuzzy set only partially:

$$0 < \mu_M < 1$$

Fuzzy expert system consists of a set of conditional statements.

	X_1	X_2	X_n	Y
1	A_{11}	A_{12}...	A_{1n}	B_1
2	A_{21}	A_{22}...	A_{2n}	B_2
3	A_{31}	A_{32}...	A_{3n}	B_3
....				
m	A_{m1}	A_{m2}	A_{mn}	B_m

Figure 4: Fuzzy expert system (Source: Own work)

Fuzzy computation is divided into three steps. First step is the fuzzification - in this phase of the computation the real input values are transformed to the linguistic variables used in the fuzzy model. Usually there are several linguistic variables assigned - between three and ten. Next step is the fuzzy inference - this step is the essence of fuzzy logic. The behavior of the system is described by rules if, and, or, then. The behavior of the system is recorded by the combination of the linguistic variables and these rules - each individual combination is called statement. One statement is the description of certain situation. The set of all statements describes the behavior of the system that is being simulated with the fuzzy model. The set of all statements is called a knowledge base.

There are various software products that facilitate the use of fuzzy logic. It is necessary to collect enough information and determine which variables will be used. Fuzzy logic enables decision makers to analyze complex situations and solve complex problems. This is a clear advantage of fuzzy logic. There are also several disadvantages. One of the disadvantages is the complexity of the process. It takes certain amount of time to collect enough information, process the information, create the statements, create the model and in the final phase it takes effort to interpret the calculated results. However the time spent on preparing the information returns as the ability to solve complex problems which are difficult to solve with other methods and approaches. Fuzzy logic has proven to be very useful for solving economical problems due to the nature of these problems and the character of the factors and variables that influence them. Sophisticated software is also available which makes the work with fuzzy variables and with the model much easier.

2.6 AVAILABILITY OF REQUIRED RESOURCES

Several resources were required in order to achieve the set research goals. This paragraph contains a list of these necessary resources. If any of these resources was unavailable then it would be difficult to reach the set goals.

- Availability of input data for testing.
- Availability of specialized software – proprietary fuzzy logic software, MATLAB.
- Graph drawing software, data collection software, data processing software.
- Java programming language.
- Online databases of real estate available for sale containing brownfield sites.
- Case studies for evaluation and comparison.
- Possibility of consultation with real estate investors.

3 SOLVING THE RESEARCH PROBLEM

3.1 PREREQUISITES FOR USING THIS RESEARCH

This research is intended for investors who are planning to purchase and redevelop brownfields. The objective of this research is to provide a decision making support method for the investors. The proposed investment evaluation method is particularly useful in scenarios where the investor chooses from a large group of investment alternatives. For example if there is more than one hundred investment alternatives. This method allows the investor to carefully analyze and compare the individual brownfields based on the hierarchy of parameters describing the brownfields. The application of similar approach based on the hierarchy of parameters was researched in (Kučerová, 2006). This research has several requirements. The most important requirement is that the investor has clear objectives and has to be able to clearly define own needs and objectives. Only then can the new method output valid recommendations that reflect the needs and objectives of the investor. If the objectives and needs are rational, logical and well defined then this new decision support method can be used. The set of parameters is defined by the investor according to the needs and objectives the investor has. Some information about the brownfield site is always available – for example the price, area, equipment, infrastructure etc. But some information is usually not known, for example the true level of contamination. The information about brownfields needs to be well structured. The information about the brownfield sites also has to be valid and up to date. There should also be enough time to collect and process all the information about the investment alternatives – if a set of for example two hundred brownfield sites should be analyzed it may take up to several weeks to collect and process the information so it can be used in the fuzzy model. Fuzzy modeling and testing of the model may also take a certain period of time.

3.2 RESEARCH TIME PLAN

This chapter contains a list of activities that were required in order to reach the set research goals. In a complex process working with large amount of information which may contain uncertain, unknown or incorrect information everything needs to be tested several times to make sure that the model and also the whole decision making support process is robust. If the proposed method of evaluation should be chosen by the real investors the method has to be reliable. It is therefore required to test different scenarios, various types of input variables and various amounts of input information. The research was conducted in three phases. First phase includes analysis of the research problem, sources of information, previous research conducted in this field etc. The second phase includes the activities related to the creation of the fuzzy model, testing and optimization of the process. Here is a detailed list of activities and milestones that had to be reached in order to reach the set research objectives.

First phase

- Analysis of the research problem and relevant literature and previous research conducted in this field.
- Analysis of the usual methods used by the decision makers and existing fuzzy models.
- Definition of research objectives.

Second phase

- Evaluation of the criteria that will be frequently used by the decision makers.
- Generation of the test data and creation of the initial fuzzy model for testing.
- Processing of the test data with the model and the evaluation of results.
- Adjustment, optimization of the fuzzy model and thorough testing.
- Development of the supporting applications for the data collection and processing.
- Development of the supporting software applications for the evaluation of results.

Third phase

- Evaluation and interpretation of the results.
- Thorough testing of the software and of the fuzzy model in different scenarios.
- Presentation of the new method to investors.

3.3 RELEVANT CRITERIA FOR THE DECISION MAKING PROCESS

The investment appraisal process requires thorough analysis of various criteria. These criteria can be divided into several groups. In this research focused on brownfield redevelopment these criteria are specific. Certain criteria are the same for a brownfield site and for any other real estate. But certain criteria are special – for example the contamination of the brownfield site plays a very important role. In this research the criteria are divided into several groups. These groups are: general information about the brownfield site, geographic criteria, economic criteria, financial criteria and criteria related to ecology. A number of criteria in each group is listed in the following table. Each criterion is described in detail in the dissertation.

Group	Description	Variable name in the fuzzy model	Unit or variable type
General	ID	-	integer
	Address	-	text
	City	-	text
	URL	-	text
	Description	-	text
Geographic	Distance from the investor	Di	km
	Infrastructure	In	%
	Specialized equipment	Se	%
	Future extensibility	Ex	%
	Availability of qualified workforce	Ps	%
	Positive attitude of local community	Pa	%
Economic	Price	Ce	Kč
	Area	Ro	m2
	Estimated costs of logistics	Do	Kč
	Estimated fixed costs	Fc	Kč
	Basic requirements	Zp	%
	Special requirements	Sp	%
Ecology	Costs of adaptation	Ad	Kč
	Required short term investments	I1	Kč
	Required long term investments	I2	Kč
	Availability of EU and state funding	Fu	%

Table 1: Evaluation criteria and corresponding fuzzy variables (Source: Own work)

3.4 SOURCES OF INFORMATION

One of the advantages this new research offers to the investors is that the system is designed to analyze a very large set of investment opportunities. In order to work with a large number of possible investments the system requires a large amount of information available. This information describes the alternative investments in detail. Each brownfield site can be described by a set of criteria. Investor chooses which criteria are relevant for the decision making process. Some information about the brownfield site may not be relevant so it is of no use to collect and store this information – redundant information would slow down the processing speed. It is possible to collect the information about all investment alternatives manually from printed materials or contact the sellers via telephone but this process is not efficient enough and very slow.

3.5 DATA PROCESSING

The files containing information about the selected brownfields have to be processed in order to use this information as the fuzzy knowledge base. A set of applications was developed in the Java programming language. These applications allow to efficiently process thousands of downloaded web pages and to extract the relevant information about the real estates in the required format. Data analysis and processing is necessary because the information data does not come from a single database or source. It would be much easier if all the information would be available in one database – but this is not the case.

Id	Id	1
Address	Ar	Rojetín
City	Ci	Rojetín
URL	Ur	http://sreality.cz/detail/prodej/komercni/vyroba/rojetin--/827106140
Description	Ds	Prodej objektu bývalého lihovaru v obci Rojetín. V objektu se nachází funkční – zakonzervovaná technologie na výrobu surového lihu, případně je možné využít technologii na výrobu biopaliv. Objekt se nachází na okraji obce a stojí na vlastním pozemku. V případě zájmu, lze dokoupit i pozemky ostatní, které jsou prozatím majetkem pozemkového fondu. Na
Distance (km)	Di	38
Price (Czk)	Ce	3300000
Area (m2)	Ro	4191

Table 2: Sample of collected and processed information about a brownfield site (Source: Own work)

3.6 STATISTICAL APPROACH

In order to check the results of the fuzzy model a statistical approach is used to calculate a set of numerical values. These calculations are performed independently on the fuzzy calculations and output different results. Classical statistical approaches do not allow the work with fuzzy input information. The fact that fuzzy information is present in the input data meant that a new method of calculation had to be used in order to obtain results which can be compared. Statistics can easily compare individual numbers or vectors of numerical values. However in this case the information about some brownfield site may not be known or may be known to be imprecise or wrong. Therefore the fuzzy model contains the option to set the value of the input variable to unknown. The individual statements of the knowledge base can be seen as four groups of variables. Each group includes different variables – for example economic, financial etc. Each group consists of several variables.

This group of variables can be seen as a vector of numerical values. It has to be noted that this vector may include a variable that does not have a number assigned in the case that the information is not available. In order to compare the numerical values and simplify the fuzzy calculation a system of fuzzy sets is used. These fuzzy sets are ordered from the least suitable value for the investor to the most suitable. Thanks to this all variables are converted from absolute values to a scale from zero to one hundred. With this simplification the individual variables and even the groups of variables can be compared with the help of a simple arithmetic average. The higher value is calculated the more suitable is the analyzed brownfield site for the investor.

The problem is that the input data includes unknown variables. The unknown variables cannot be set to zero because the numerical value zero signifies the least suitable possible value. Instead the variable is left empty. When a simple arithmetic average would be calculated from such vector it would include only those variables which have a set value and so the calculated average would not be correct. For example if only one variable is known and its numerical value is ninety then the calculated average from this group of variables would also be ninety – which would mean that the investor would get incorrect information about the brownfield site. The site would look like it suits the requirements very well but instead very little true information would be available and the brownfield.

In order to solve this problem additional numerical value is calculated. This value records the ratio of known to unknown information. With this calculation the information about unknown variables is precisely recorded. The simplest statistical method to analyze the input information is therefore to calculate two numerical values for each group of variables for each brownfield site. For four groups of variables eight numerical results are calculated. With these eight values which include four arithmetic averages and four ratios of known to unknown information the brownfield sites can be relatively easily compared.

Calculation of the arithmetic mean:

$$A = \frac{1}{n} * \sum_{i=1}^{n} x_i$$

Calculation of the known information ratio:

$$KI = \frac{Number\ of\ known\ parameters}{Number\ of\ total\ parameters}$$

The calculated results of this statistical method should of course output the same recommendations based on the requirements of the investor. However it is clear that this statistical calculation does not provide the large amount of information about the knowledge base compared to the approach which uses the special fuzzy software. The special software allows the identification of existing similarities between statements in the knowledge base. Also the results of the fuzzy model can be visualized, analyzed and interpreted graphically. It would be possible to calculate the overall average and ratio of known to unknown information for each individual brownfield site but such values would be very inaccurate and it would not be possible to perform a direct comparison. This limitation is caused by the complexity of the input information describing the investment alternatives. Therefore it would not be possible to use only the statistical approach for this research problem. Several different approaches are required in order to confirm the results calculated by one method or approach.

	Arithmetic average				Known information			
Statement	Geographic	Economic	Financial	Ecology	Geographic	Economic	Financial	Ecology
1	66,67	58,33	72,5	70	1	1	1	1
4	60	66,67	87,5	60	1	1	1	1
12	51,8	54,25	26	72	0,83	0,67	0,4	0,5
16	55,2	44,67	44	70,75	0,83	0,5	0,8	1
20	69,5	32,33	38	54	1	1	0,4	0,75

Table 3: Sample results obtained with the statistical approach for several statements (Source: Own work)

3.7 FUZZY MODEL

The fuzzy model is the key component in this research. Fuzzy models were successfully used to solve other economic problems including (Brož & Dostál, 2012) and (Bočková et al., 2012). The model allows sophisticated analysis and evaluation of the input data. The data and the evaluation criteria have to be preprocessed and converted to a special format that is used by the proprietary fuzzy logic software used in this research. The collected information has to be first assigned to fuzzy sets. These sets can have a different resolution as can be seen in the following two figures.

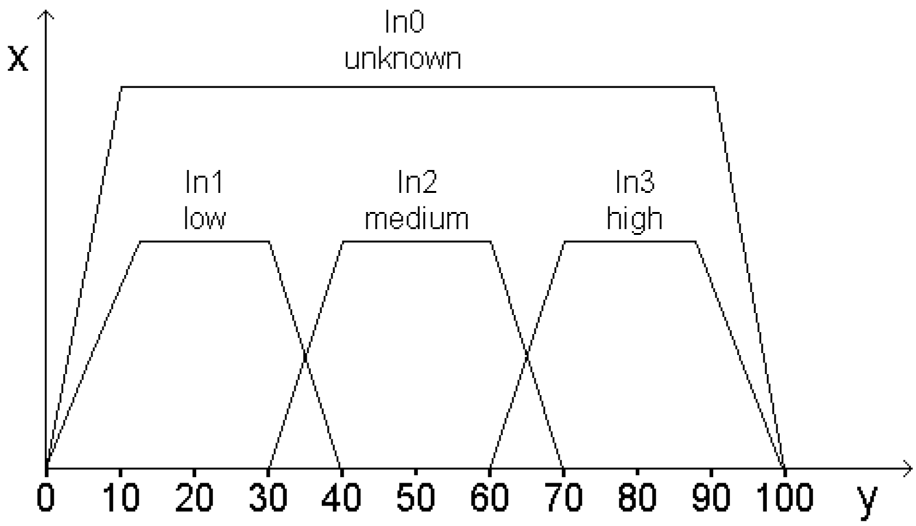


Figure 2: Grades of membership in four fuzzy sets (Source: Own work)

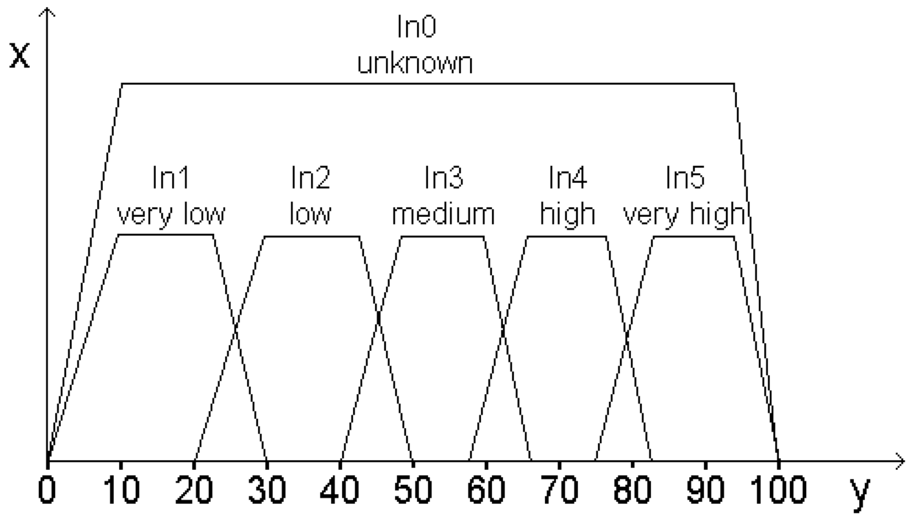


Figure 3: Grades of membership in six fuzzy sets (Source: Own work)

Following table records the individual fuzzy sets and intervals used for the area of the real estate – measured in square meters. Instead of listing all twenty tables just one was selected for this chapter. In order to simplify the fuzzy model a different order of fuzzy sets has to be used for criteria where higher value is worse for the investor. For example prices and costs have this reversed order. This measure allows the use of common statistical methods. Without this measure the statistical calculations would output incorrect results. This reverse order also makes it easier for the fuzzy software to work with the fuzzy knowledge base. Inverse proportion in the input data and fuzzy sets would make the processing even more complex as it would be required to record this information for each variable.

Fuzzy set	Area in square meters	
	Lower limit	Upper limit
Ro0	unknown	
Ro1	0	199
Ro2	200	399
Ro3	400	599
Ro4	600	999
Ro5	1000	1999
Ro6	2000	4999
Ro7	5000	19999
Ro8	20000	49999
Ro9	50000	unlimited

Table 4: Fuzzy sets and assigned intervals (Source: Own work)

When the fuzzy logic software is launched a set of parameters is inputted. These influence how the application processes the fuzzy knowledge base. These parameters for example influence the number of brownfields that will be included in the result. It is also possible to influence the threshold for finding similarities in the input data. Same model with different settings can result in very different results – it depends on the parameters that are entered into the software before the calculation begins. The fuzzy model has certain limitations. The most significant limitation is the amount of the input data and criteria that can be entered into the model.

The limitations will be discussed in greater detail in a special chapter. It is also possible to interact with the fuzzy model. The processing of the input data is not only a single operation performed by the computer but it can also be a fuzzy dialogue between the user and the fuzzy model. The model is processed several times based on the reactions of the user who analyzes the intermediate results. The fuzzy dialogue will be discussed in a special chapter. A set of brownfields specifications represents a complex and very vaguely defined system. Once the information about the investment alternatives is collected and processed a single table is created. This table contains details describing the individual brownfields. Each brownfield site is described using the same variables - this allows the initial analysis of the input data before the information is converted for the fuzzy model. The fuzzy model does not directly work with absolute values contained in the input data. The information has to be converted into statements. The set of fuzzy statements describing the individual brownfields is studied. These statements consist of combinations of variables describing the intervals containing the absolute value describing a single variable of a single brownfield. Names of these intervals consist of codes combined with numeric values and are ordered from least suitable for the investor to the most suitable. This order simplifies significantly the fuzzy model as indirect proportion of some input variables would make it much more complicated for the fuzzy model to compare the individual statements.

If a certain variable is unknown a special interval is used. The name of this interval contains a zero. This special interval plays a very important role in the fuzzy model. Thanks to this interval the model can work with brownfields which are vaguely described because there is not enough information available. An example of several statements from the knowledge base can be seen in the following table. There are 101 statements representing 101 investment alternatives. Because the knowledge is so large only statements 8 to 17 were selected for this chapter. The whole brownfield fuzzy knowledge base can be found at the attached CD. Di3, see upper left corner of the following table, is a fuzzy set. Once the knowledge base is created it is processed by the fuzzy logic software. This software reads the knowledge base and performs calculations which analyze and compare the individual statements. The software outputs a file containing the numerical representations of similarities between individual statements.

8	Di3	In5	Se9	Ex9	Ps5	Pa8	Ce9	Ro9	Do4	Fc5	Zp5	Sp8	Ad9	I14	I27	Fu3	Po9	Be6	Er9	Fe9	1
9	Di5	In9	Se8	Ex2	Ps6	Pa8	Ce9	Ro9	Do6	Fc6	Zp9	Sp7	Ad4	I17	I24	Fu7	Po9	Be9	Er6	Fe9	1
10	Di6	In9	Se6	Ex6	Ps9	Pa9	Ce5	Ro9	Do5	Fc8	Zp5	Sp6	Ad9	I18	I29	Fu9	Po8	Be9	Er9	Fe9	1
11	Di0	In7	Se0	Ex0	Ps9	Pa0	Ce3	Ro6	Do4	Fc7	Zp0	Sp8	Ad1	I19	I20	Fu0	Po9	Be0	Er6	Fe0	0,8
12	Di4	In7	Se8	Ex6	Ps0	Pa4	Ce4	Ro7	Do0	Fc0	Zp3	Sp9	Ad3	I10	I20	Fu0	Po7	Be0	Er0	Fe8	0,8
13	Di3	In3	Se3	Ex0	Ps3	Pa0	Ce0	Ro9	Do8	Fc6	Zp5	Sp0	Ad0	I13	I29	Fu2	Po9	Be0	Er0	Fe4	0,8
14	Di4	In4	Se9	Ex0	Ps4	Pa0	Ce0	Ro2	Do6	Fc4	Zp0	Sp9	Ad0	I13	I20	Fu0	Po9	Be0	Er3	Fe1	0,8
15	Di0	In6	Se4	Ex0	Ps5	Pa2	Ce8	Ro1	Do9	Fc9	Zp5	Sp3	Ad0	I14	I20	Fu3	Po8	Be4	Er9	Fe0	0,8
16	Di0	In5	Se3	Ex6	Ps6	Pa9	Ce6	Ro0	Do1	Fc7	Zp0	Sp0	Ad7	I12	I20	Fu6	Po9	Be3	Er7	Fe9	0,8
17	Di4	In2	Se9	Ex0	Ps0	Pa1	Ce2	Ro9	Do5	Fc7	Zp8	Sp0	Ad4	I19	I28	Fu5	Po3	Be0	Er5	Fe0	0,8

Table 5: Several example statements of the fuzzy knowledge base (Source: Own work)

Special software was developed to simplify the interpretation of the results. The task of this software is to convert the information about the similarities into a similarity graph. This similarity graph can be seen in the next chapter. The resulting similarity graph is an opportunity to easily find other brownfields which are similar to a certain degree. The fuzzy knowledge base is analyzed in several ways in order to determine the ideal investment alternative based on the requirements formulated by the investor. The whole model can be found in Appendix 1 in dissertation. The fuzzy logic software uses following equations and calculations to find intersections and similarities between fuzzy sets. Because there are twenty variables in the model the software calculates these intersections and similarities in twenty-dimensional space.

The similarity of two fuzzy sets can be mathematically described as:

$$s(n, V, W) = \min_{1 \leqslant j \leqslant n} \left(\max_{X_j} \left(\min \left(\mu_{Vj}(X_j), \mu_{Wj}(X_j) \right) \right) \right)$$

where

$$\max_{X_j} \{ \min (\mu_{Vj}(X_j), \mu_{Wj}(X_j)) \}$$

represents the fuzzy intersection between V_j and W_j according to (Dohnal et al., 1996).

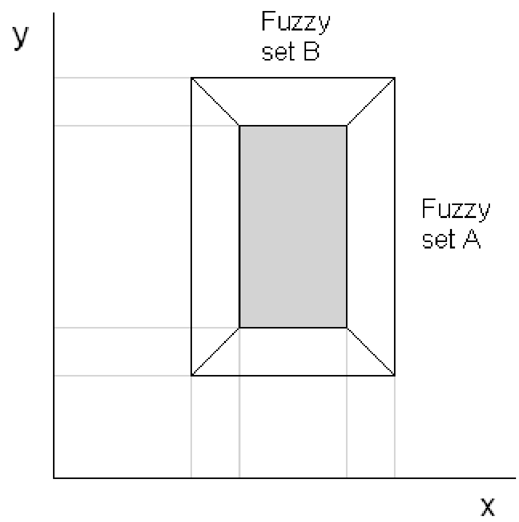


Figure 4: Intersection of two fuzzy sets in a two-dimensional space (Source: Own work)

It is also possible to use MATLAB and its Fuzzy logic toolbox for the implementation of a fuzzy model. The implementation of various economic models in MATLAB is described in (Dostál, 2008). After several tests it became apparent that the fuzzy model contains too many input variables and statements. The resulting model in MATLAB would be too complex and would not yield the desired results without adjustments to the model. The large number of statements in the knowledge base led to conflicts in rules which the fuzzy toolbox generates. Instead the special fuzzy logic software was used for the implementation of the model. The Fuzzy logic toolbox in MATLAB is designed primarily for models that use lower number of input variables and have fewer statements in the knowledge base. Following figure demonstrates a simple fuzzy model in the MATLAB fuzzy toolbox - it's input are the four groups of variables described in this research.

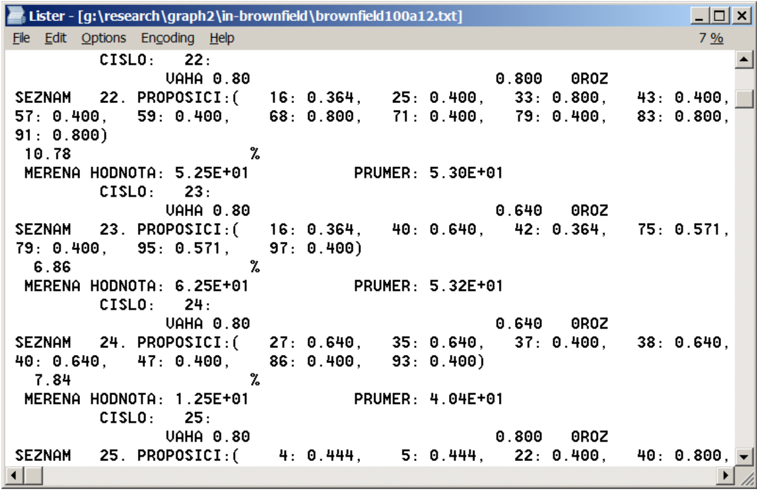


Figure 5: Output data of the fuzzy logic software containing information about calculated similarities between individual statements (Source: Own work)

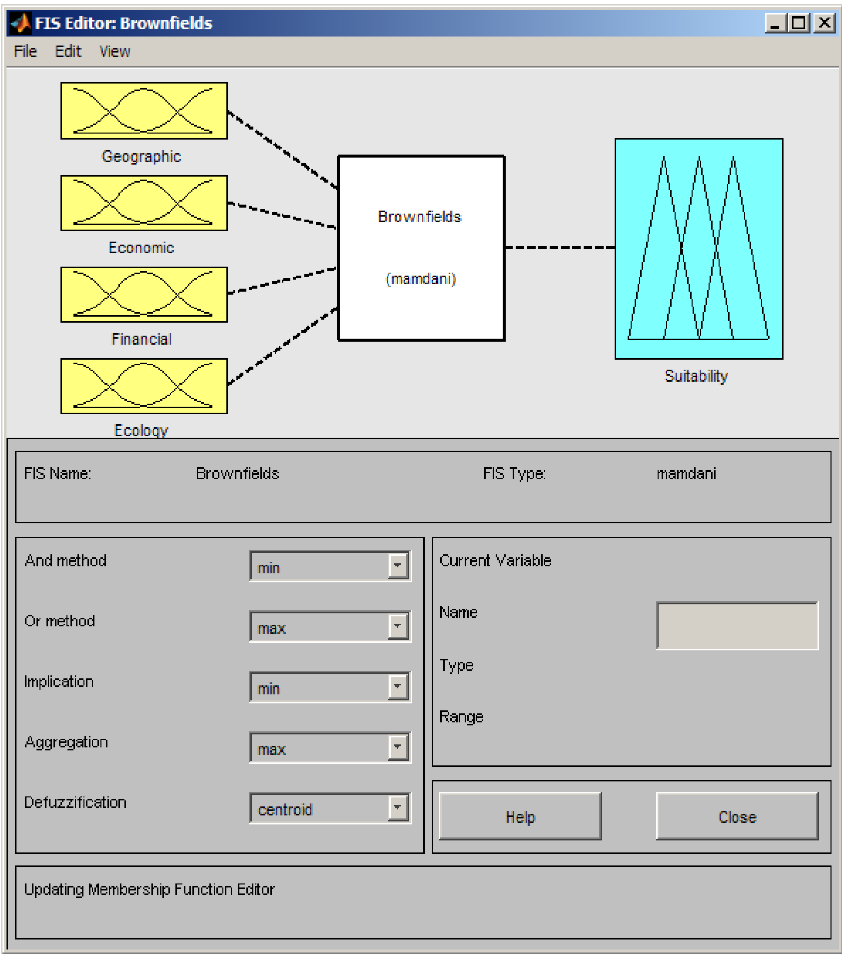
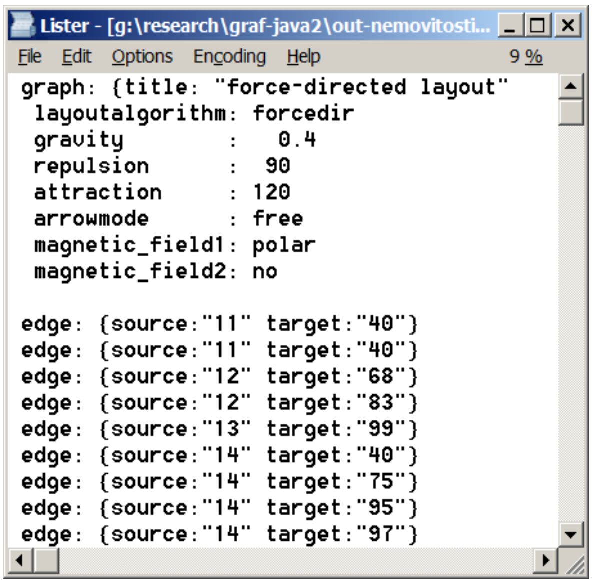


Figure 6: Sample fuzzy model implemented in the MATLAB Fuzzy Toolbox (Source: MATLAB)

3.8 EVALUATION AND INTERPRETATION OF RESULTS

The basic concept of fuzzy logic is easy to understand, but the process becomes complex as large amount of information is loaded into the model. It is necessary to carefully interpret the results the fuzzy logic software calculates and outputs. A special application had to be developed – the task of this program is to filter the data and to look for certain patterns that indicate interesting information and relations. Thanks to this software is possible to quickly process the output data and to display only the information matching the requirements. It is also very helpful to visualize the results of the fuzzy software. A sophisticated and versatile graph drawing software called AiSee is used to visualize the relations and similarities between the statements in the knowledge base.




```
graph: {title: "force-directed layout"
 layoutalgorithm: forcedir
 gravity        :   0.4
 repulsion      :  90
 attraction     : 120
 arrowmode      : free
 magnetic_field1: polar
 magnetic_field2: no

edge: {source:"11" target:"40"}
edge: {source:"11" target:"40"}
edge: {source:"12" target:"68"}
edge: {source:"12" target:"83"}
edge: {source:"13" target:"99"}
edge: {source:"14" target:"40"}
edge: {source:"14" target:"75"}
edge: {source:"14" target:"95"}
edge: {source:"14" target:"97"}
```

Figure 7: AiSee graph source file automatically generated from the results of the fuzzy model (Source: Own work)

The graph displays all statements in the knowledge base. Some statements are similar to each other and some are so different that they do not have any similarity to any other statement in the knowledge base. These findings are very useful and help to interpret the output of the fuzzy software. The software creates a large graph containing nodes and edges. This similarity is displayed in the graph as an edge between two nodes. In the center of the graph, clusters of similar elements appear. Large clusters and cores of clusters are closer to the center of the graph. Unique statements which are not similar to any other statements are displayed further away from the center of the graph. To visualize the results of the fuzzy model is very helpful and allows users to quickly get an overview of the data that was evaluated with the fuzzy model. The model is calculated many times with different settings which reflect the requirements of the investor. Each time the software outputs different results and also the resulting graphs look differently. Several similarity graphs are included in this chapter. Each calculation of the fuzzy model produces different results and of course a different similarity graph. Dozens of similarity graphs were generated during the testing phase. Another application was created in order to filter only the strong similarities based on the user input.

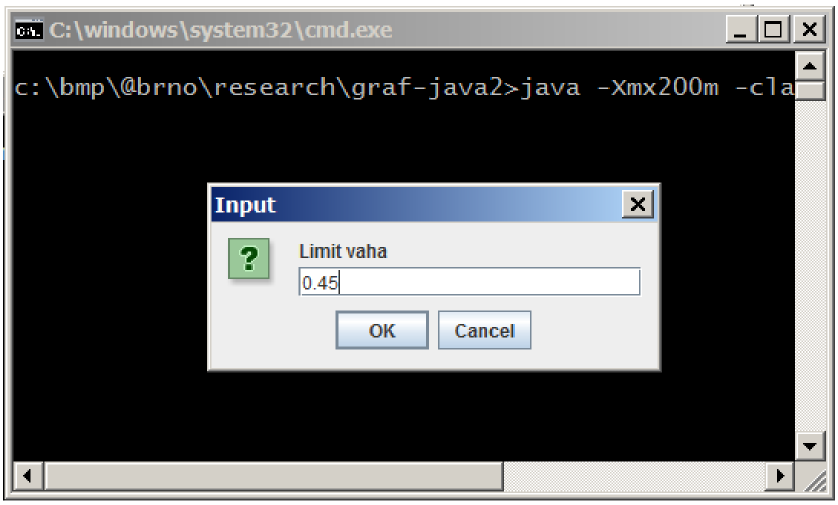


Figure 8: Software application for filtering relations with a set value (Source: Own work)

The graph drawing software does not include the option to set the strength of an edge in the graph so it was necessary to process the file with information about similarities so that only those similarities which fit the set criteria will be later displayed in the graph. The applications which were programmed for this process can be found on the attached CD. The developed applications facilitate the process of visualization and interpretation of the results tremendously. Without these applications and without the graph drawing software the processing and interpretation of the results would be very time consuming. Graphs generated with these applications are steadily being used also in other researches which involve complex fuzzy models such as the one in this research.

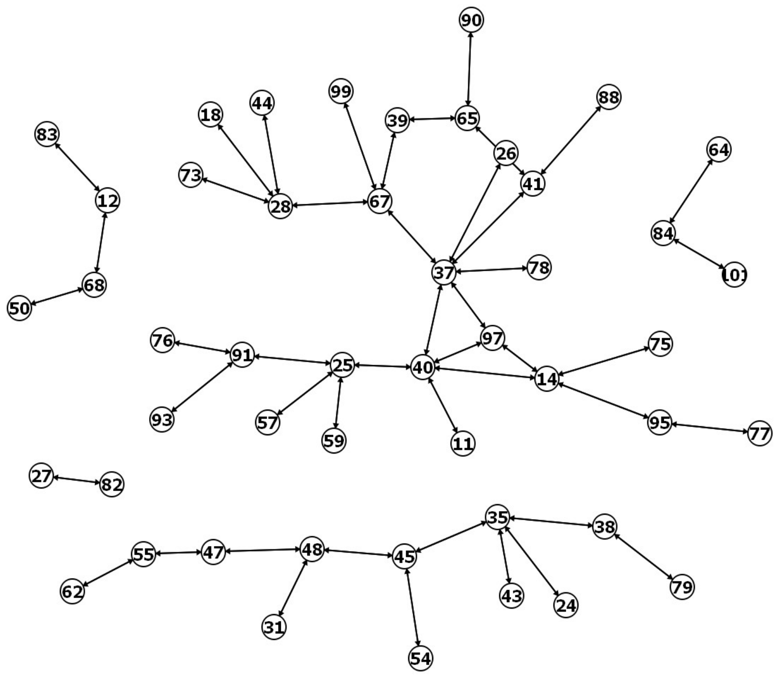


Figure 9: Similarity graph with stretching equal to 0
(economic and financial variables included) (Source: Own work)

In order to visualize the multidimensional input data of the fuzzy knowledge base it is very useful to generate a 3D scatter plot in MATLAB software. However this visualization is not perfect as it is not possible to visualize this complex multidimensional input data only in three dimensions. The fuzzy knowledge base in this research has twenty variables so in order to truthfully visualize this data a twenty dimensional plot would have to be used. Even so it would be difficult to display individual statements as they contain variables with unknown value. A simplified matrix had to be generated for three sets of input criteria. This matrix had to be calculated using statistical methods in order to allow this simplified 3D visualization. The 3D scatter plot could also be used to easily filter out the best investment alternatives because they are the nearest to the edges of the plot. Slight disadvantage of this method is that it omits the unknown values of some criteria in the input knowledge base. In order to solve these limitations a comparison of results with results of other methods would have to be used for the correct representation of the results. The color and size of each point in the scatter plot can be set in order to represent its value relative to one of the axes of the plot.

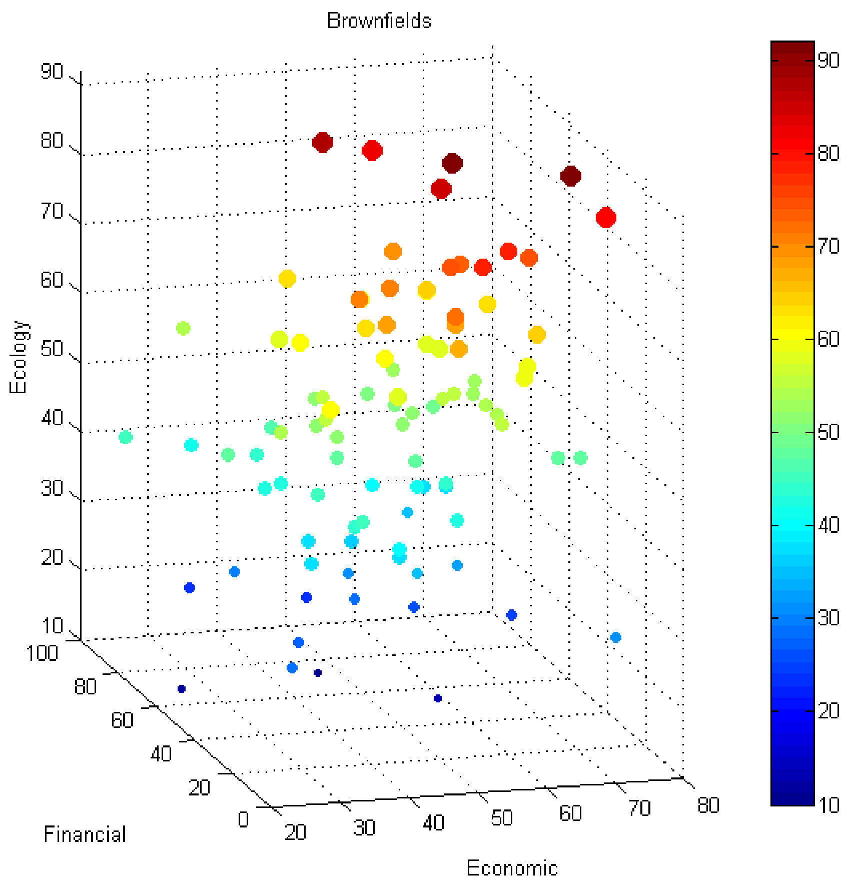


Figure 10: 3D scatter plot generated in MATLAB for average values of three groups of variables (Source: Own work)

3.9 TESTING OF THE FUZZY MODEL

Before the method is offered to investors it was necessary to perform thorough tests. Several applications for data collection, processing and for the interpretation of the results were created – it was also necessary to test these new applications. The objective of this research is to create a very flexible and robust method that can deal with the most situations and scenarios that will occur. The model has to work not only with a very small set of input data and few criteria but also with a large set of input data containing hundreds of real estates. It is possible to predict the requirements that the investors will have to a certain degree. But to be safe many different scenarios had to be simulated to ensure that there will not be difficulties and unanswered questions when real investors use this method to analyze and evaluate their set of investment alternatives. Fuzzy logic allows to process data which contains many unknown or uncertain variables. While testing the model it was necessary to supply test data that is similar to the data that will be supplied by the investors or collected from other sources.

There are several different methods how to test the validity of the results supplied by the fuzzy model. One of these methods is to manually check the input data and look for brownfields that logically suit best the requirements of the investor. These brownfields should be included in the reduced set outputted by the fuzzy software. However a situation can occur when the parameters of selection do not have same importance. For example the user can have special requirements related to ecological parameters. In this case it is possible to manually adjust the data and use weighted average. There has to be a similarity between the results obtained manually and the results produced by the fuzzy software to a certain degree. Another method how to test the validity of the results supplied by the fuzzy software is to put several ideal investment alternatives into the input data. These brownfields have to be included in the resulting set. There are several other methods how to test the validity of the results for example to use statistical methods etc. To ensure high reliability and flexibility of the model it is always necessary to perform several independent tests. Feedback of the investors during this process significantly improves the obtained results as some important details tend to be omitted frequently when the key requirements and objectives are initially formulated by the investor.

3.10 FUZZY DIALOGUE

Fuzzy logic software used in this research allows a type of dialogue with the fuzzy knowledge base. The application of fuzzy dialogue in accounting was researched in (Kába, 2009). The fuzzy dialogue in this research starts with a fuzzy model and a query formulated by the user. Based on the results obtained from the software a new query is formulated for the software. This second query returns a different result than the first query. The user who formulates the queries has an objective and modifies the queries based on the returned results so that the results are gradually refined toward the objective. Fuzzy dialogue is a powerful option to refine the information obtained from the fuzzy software. The dialogue can be a series of two or more consecutive queries with the same model producing different results in each phase of the fuzzy dialogue. Fuzzy dialogue can be used in a combination with other methods to optimize the whole process of reducing the set of all available investment alternatives. Following table shows the sequence of fuzzy queries and the results calculated by the fuzzy software. Following figure demonstrates the center of gravity of two fuzzy sets which is calculated in a fuzzy dialogue.

Query	Dependent variable	Fuzzy set	Center of gravity	Limiting variable
1	7	Ce6	0,67	1
1	7	Ce6	0,68	1
1	7	Ce2	0,05	8
2	8	Ro0	0,12	11
2	8	Ro8	0,15	9
2	8	Ro0	0,15	9
3	1	Di5	0,14	9
3	1	Di5	0,26	9
3	1	Di0	0,12	11
4	2	In9	0,28	7
4	2	In5	0,28	8
4	2	In3	0,28	10
4	2	In6	0,28	11
4	2	In2	0,55	9
4	2	In0	0,28	8
4	2	In1	0,28	17

Table 6: Fuzzy queries and calculated results (Source: Own work)

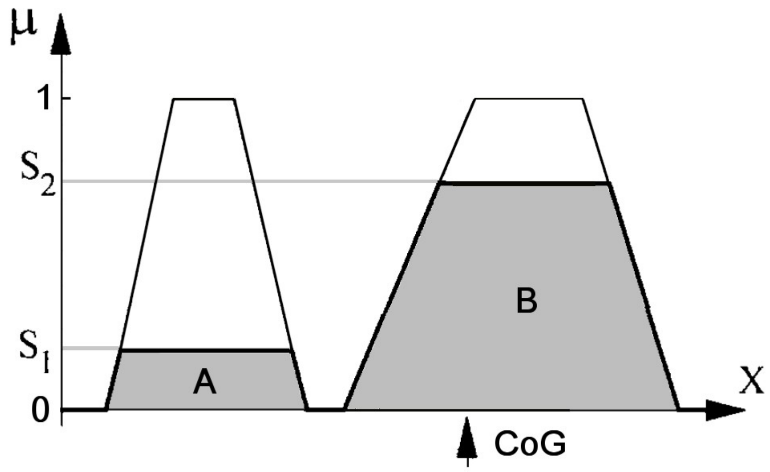


Figure 11: Center of gravity of two fuzzy sets (Source: Own work)

3.11 IMPLICATIONS AND LIMITATIONS OF THIS RESEARCH

It is also important to consider the limitations of this research. The fuzzy model outputs a result that needs to be interpreted and analyzed. The goal is not to recommend a single investment alternative to the investor but to analyze and evaluate the set of possible investments and to reduce this set to a much smaller set. For example if there will be several hundred possible investments the task of the designed fuzzy model is to reduce this set to a small set containing only about one or two dozen investment alternatives which can later be thoroughly analyzed with conventional methods – for example financial indicators can be used in order to calculate the true value of the asset. This reduction is based on the criteria and requirements that are inputted into the model along with the investment alternatives recorded as statements in the fuzzy knowledge base. The processing speed of the computer is a major limitation in this research. The complex operations performed by the proprietary fuzzy logic software require a lot of processing power.

The processing of the model that contains more than four hundred investment alternatives with twenty input criteria takes more than one hour. If the input set is larger, then this set has to be reduced with the help of other methods before the fuzzy calculation is performed. For example brownfields with too many unknown parameters can be removed from the input set. If there are too many unknown variables the statement tends to be similar to other statements which also have a lot of unknown variables. Another limitation is the complexity of the process. The process is too complex and cannot be performed by a single software application. Even with all the support software developed and ready to use it takes several days to perform all necessary phases of the process including collection of the input data, processing of the input data, creation of the model, fuzzy computation of different scenarios, interpretation of the results and formulation of the recommendations for the investor which include a reduced set of investment alternatives. The current set of variables used in the model should suit the requirements of most investors who plan to redevelop a brownfield site. But it is clear that some investors may have different requirements and need to include a different set of variables which record the information important for their particular needs. The model is designed so it is easy to change the set of the input variables. The changes occur especially during the initial phases of the whole process – especially during the processing of the data. The fuzzy calculation and interpretation of the results stays the same even when the model uses a different set of variables. Another limitation is that the fuzzy model requires the precise definition of requirements and objectives by the investor. Without precise objectives and requirements the fuzzy model cannot recommend the ideal investment alternatives. If an investor requires information about the investment alternatives that is not available in any database where it can be downloaded by the software written for this research it is necessary that the investor inputs this information into the fuzzy knowledge base. News related to this research are available online at http://www.dicts.info/files/fuzzy .

3.12 PROPOSED METHOD

The proposed method consists of a sequence of following steps:

1. Definition of the objectives and requirements by the investor.
2. Initial analysis of the input from the investor and of available information about the investment alternatives.
3. Definition of the relevant parameters for the fuzzy model.
4. Data collection and processing.
5. Creation of the fuzzy model.
6. Thorough testing of the fuzzy model with different settings and scenarios and consultation with the investor.
7. Interpretation of the results.
8. Formulation of recommendations for the investor.

Each of these steps includes complex operations which are facilitated significantly by the software designed for this research, particularly the process of data collection and data processing. Performing these tasks manually with the amount of information the fuzzy model is able to process would be very time consuming. The investor will certainly request at least one different criterion than those used for the initial fuzzy model in this research to be present in the fuzzy model. Therefore each process and software in this research was designed with flexibility in mind. Investors will be satisfied only if the proposed method is flexible enough for their individual needs.

3.13 FUTURE RESEARCH

This chapter contains information about future research papers and about continuation of this research in the future. Several research papers about this research are now in the process of review in scientific journals or are ready for publication. The mentioned research papers deal with these topics. A simple chaos analysis of brownfield knowledge bases. Investment appraisal - Generic evaluation criteria for brownfields. Fuzzy logic modeling as a decision making support for investment appraisal. Economic, environmental and social benefits of brownfield redevelopment.

This research will be continued and extended in the future because of its importance for investors and because brownfield redevelopment promotes sustainable development and smart growth. As soon as the investors request the use of this method for a real decision making problem. New selection criteria, requirements and objectives will be formulated by the investor. These expected new conditions will lead to modification and optimization of the process as it will be important to perform new currently unknown tasks. The new method is designed with flexibility in mind. The method proposed in this research can of course be modified so it uses fuzzy knowledge base with different input information – as long as this input information consists of a matrix of measured or estimated values. This makes this research particularly useful as decision makers in different fields may be able to benefit from this research as well as the investors who are planning to redevelop brownfield sites. In the initial phases of this research, it was considered to use, not only the combination of fuzzy logic and statistical methods, but also to use other methods like for example neural networks, genetic algorithms and other approaches. These methods may be researched as well in the future.

4 CONTRIBUTION AND UTILITY OF THIS RESEARCH

The researched method facilitates the decision making process about real estate investment especially in cases where there are many possible alternative decisions and a large number of criteria. The fuzzy model does not recommend a single real estate but reduces the large set of input real estates to a much smaller set of real estates based on the set criteria. It is then much easier for the decision makers to choose from this reduced set of alternative decisions. However the correctness of the results is strongly influenced by the quality of input information. If important details are not inputted into the model then the results may not be precise or may be skewed. It is therefore essential to input true and unbiased information and carefully create the set of all relevant criteria for the particular decision. Furthermore the qualified guesses bring a certain measure of uncertainty into the process as well.

Theoretical contribution of this research:

1) The creation of a complex method based on fuzzy logic that facilitates the decision making process about large investments - particularly brownfield redevelopment.
2) Findings leading to the optimization of complex processes related to decision making which include data collection, data processing, modeling, simulation, visualization and interpretation of results.
3) Definition of a hierarchy of generic evaluation criteria that can be used by investors in scenarios which include brownfield redevelopment.

Practical contribution of this research:

1) The creation of complex, robust and reliable method which facilitates the decision making process in cases which involve large amount of input information and a large set of alternative investment decisions. This new method will be presented to investors and offered as a service due to its complexity.
2) Creation of versatile software tools which are used for a variety of tasks in this research.
3) The researched method is very flexible and versatile - if a set of conditions is met this method can be used for other tasks in the real world which involve an evaluation of a large set of alternatives with a hierarchy of criteria.
4) Software created for this research is universal and has already been used in order to perform specific tasks in several other research projects. For example tasks such as the automated data collection, data extraction or data conversion are tasks frequently requested by fellow colleagues who perform these operations frequently in other research projects.
5) Software for automated processing and visualization of complex research data has already been used for the visualization of results in several published research papers by my colleagues. Creation of this software allows to interpret the complex results of the special fuzzy logic software more easily.

Pedagogic contribution of this research:

1) The researched method will be presented to professors teaching subjects related to investing and investment evaluation.

CONCLUSION

The main objective of this research was to design a robust and flexible method that facilitates the complex processes combining decision making, investment and brownfield redevelopment with the help of fuzzy logic and modeling. Due to a high degree of complexity of the researched problem it was necessary to think about the whole process and to try to modify and automate each individual process so that it would require minimal input from the investor. With a powerful decision support method such as this one the decision makers are able to process much larger amount of information and decide in a shorter time. Especially the process of data collection, analysis and processing can be optimized with the custom software written for these tasks. Thanks to the software created in this research a large amount of information about large number of investment alternatives can be collected in a short time. This data is then analyzed, processed and a fuzzy model is created. This model is then processed and a list of requirements and objectives defined by the investor is used to find the investment alternatives that match the set requirements. The possibility of customization of this set of relevant criteria is very important as different companies have different requirements. The model then reduces the set of possible investment alternatives and finds a small set that suits the set requirements the best. Unknown and imprecise information is not a problem for fuzzy logic. This makes this research particularly useful as almost no brownfield site or any other real estate is described precisely by the seller. The proposed method is universal and with certain modifications can be used as a decision making support for other complex problems. Unlike other methods the proposed method has only a few requirements and limitations. After an extensive testing and optimization the new method will be offered as a service to real investors.

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2006 - present IT support of research projects, FBM, BUT Brno, Czech Republic

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2007 - present electronic questionnaires with large number of respondents
2002 - present administrator of 3 Internet portals (languages and e-learning)
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ABSTRACT

This dissertation focuses on decision making, investing and brownfield redevelopment. Especially on the analysis, evaluation and selection of previously used real estate suitable for commercial use. The objective of this dissertation is to design a universal method that facilitates the decision making process with many possible alternatives and large number of relevant parameters influencing the decision. The proposed method is based on the use of fuzzy logic, modeling, statistic analysis, cluster analysis, graph theory and sophisticated methods of information collection and processing. New method allows decision makers to process much larger amount of information and evaluate possible investment alternatives efficiently.

ABSTRAKT

Tato disertační práce se zaměřuje na problematiku investování a podporu rozhodování pomocí moderních metod. Zejména pokud jde o analýzu, hodnocení a výběr tzv. Brownfieldů pro jejich redevelopment (revitalizaci). Cílem této práce je navrhnout metodiku, která usnadňují rozhodovací proces s mnoha možnými alternativními rozhodnutími. Proces rozhodování je v praxi komplikován též velkým počet relevantních parametrů ovlivňujících konečné rozhodnutí. Navržená metodika je založena na využití fuzzy logiky, modelování, statistické analýzy, shlukové analýzy, teorie grafů a na sofistikovaných metodách sběru a zpracování informací. Nová metodika umožňuje zefektivnit proces analýzy alternativních investic a zpracovat mnohem větší objem informací. Ve výsledku tak bude zmenšen počet prvků množiny nejvhodnějších alternativních investic na základě hierarchie parametrů stanovených investorem.