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FACULTY OF BUSINESS AND MANAGEMENT
FAKULTA PODNIKATELSKÁ

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ÚSTAV EKONOMIKY

THE APPLICATION OF FUZZY LOGIC FOR RATING OF SUPPLIERS FOR THE FIRM

APLIKACE FUZZY LOGIKY PŘI HODNOCENÍ DODAVATELŮ FIRMY

MASTER'S THESIS
DIPLOMOVÁ PRÁCE

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Theoretical basis of the work
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DOSTÁL, P. Advanced Decision Making in Business and Public Services. Brno:CERM, 2011. 168 s. ISBN 978-80-7204-747-5.

HANSELMAN, D. a B. LITTLEFIELD. Mastering MATLAB. Pearson Education International Ltd., 2012. 852 s. ISBN 978-0-13-185714-2.

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ABSTRAKT

Cílem této diplomové práce je navrhnout vhodnou metodu pro vyhodnocení dodavatelů průmyslových větráku pro společnost První brněnská strojírna a.s. (PBS Brno). Společnost existuje více než 200 let na trhu a má více než 100 dodavatelů po celém světě. Proto je potřeba navrhnout adekvátní systém hodnocení dodavatelů. Pro vyhodnocení budou použité programy MS Excel a MATLAB.

ABSTRACT

Aim of this diploma thesis is to recommend appropriate method how to evaluate suppliers of industrial fans for První brněnská strojírna a.s. (PBS Brno). The company has already existed for more than 200 years and has more than 100 suppliers all over the world. Therefore, there is need for adequate evaluation method. For the evaluation MS Excel and MATLAB programs will be used.

KLÍČOVÁ SLOVA

Fuzzy logika, rozhodovací proces, hodnocení dodavatelů, cena, kvalita, MS Excel, MATLAB.

KEYWORDS

Fuzzy logic, decision-making process, evaluation of suppliers, price, quality, MS Excel, MATLAB.

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Brno 12th July 2016

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Bc. Sergiy Mykhaylyk

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CONTENT

INTRODUCTION	10
1 EXECUTIVE SUMMARY	11
2 THEORETICAL FOUNDATIONS	13
2.1 Evaluation of suppliers.....	13
2.1.1 Purchase process	14
2.1.2 Factors influencing purchase decision	14
2.1.3 Purchase phases	14
2.1.4 Types of suppliers	15
2.2 Fuzzy logic (FL).....	16
2.2.1 Fuzzy sets.....	16
2.3 MS Excel.....	20
2.4 MATLAB.....	23
2.4.1 Fuzzy Logic Toolbox.....	24
2.4.2 MF Editor.....	26
2.4.3 Rule Editor	27
2.4.4 Rule Viewer	28
2.4.5 Surface Viewer	29
3 PROBLEM ANALYSIS AND CURRENT SITUATION	30
3.1 První brněnská strojírna, a.s.	30
3.1.1 Current method of suppliers evaluation.....	31
3.1.2 List of present suppliers	31
3.1.3 Suppliers evaluation criteria	36
4 PROPOSALS AND CONTRIBUTION OF SUGGESTED SOLUTIONS	39
4.1 Fuzzy model in MS Excel.....	39

4.1.1	Fuzzification	39
4.1.2	Rule construction	41
4.1.3	Evaluation of supplier	42
4.1.4	Avoiding errors during input	43
4.1.5	Defuzzification.....	44
4.2	Fuzzy model in MATLAB	45
4.2.1	Fuzzification for Price + Finance.....	46
4.2.2	Fuzzification for Delivery Terms	48
4.2.3	Fuzzification for Quality + Innovation	50
4.2.4	Fuzzy rule construction.....	52
4.2.5	Evaluation process	54
5	RESULTS	58
5.1	MS Excel results	58
5.2	MATLAB results	60
5.3	Comparison between MS Excel and MATLAB	62
6	DISCUSSION	64
7	CONCLUSION.....	66
	REFERENCES	68
	LIST OF ABBREVIATIONS	70
	LIST OF TABLES	71
	LIST OF PICTURES	72
	LIST OF APPENDICES.....	74

INTRODUCTION

People are making number of decisions on the daily basis. In the business world it is not the difference. Being the manager it is all about making decisions. This topic triggered my attention because my mother started to work for the company which provide engineering services for different types of industrial boilers. Company called První brněnská strojírna a.s.

It is certainly important to have reliable suppliers. Without deliveries on time you cannot start with the assembling of the whole project. Entire planning process is depending on the deliveries of parts.

Also it is enormous responsibility for purchasing managers to choose right supplier. There are plenty of factors which are needed to be taken into consideration. Adequate decision making process would be useful tool for purchase managers. Such decision making process includes using of genetic algorithms, neural networks or fuzzy logic. Advantage of such system is ability to process huge amount of data and also flexibility.

This diploma thesis is divided into three parts. Theoretical part is focused on the supplier evaluation process, basics of the fuzzy logic, principles of the fuzzy logic and explanation of the usage of MS Excel and MATLAB.

Afterward in the analytical part PBS Brno is briefly presented following by presentation of possible supplier. Total of seven suppliers are chosen for the evaluation. In the end of the analytical part chosen evaluation criteria are discussed.

Results will be compared between both systems. Followed by conclusion and recommendations. Most important findings will be highlighted.

1 EXECUTIVE SUMMARY

Main aim of this diploma thesis is to create fuzzy models for evaluation of the suppliers. Purpose of this diploma thesis is to evaluate current suppliers by using fuzzy logic.

Theoretical part is focused on the supplier evaluation process, basics of the fuzzy logic, principles of the fuzzy logic and explanation of the usage of MS Excel and MATLAB.

In the analytical part company was presented with target purchase product. Seven current suppliers which are currently used for supply of the target product were briefly presented. At the end criteria for evaluation were discussed.

First of the fuzzy models were created in the MS Excel using matrixes, scalar count and condition formatting. Output of this fuzzy model is evaluation table which displays final score for each supplier. With usage of conditional formatting table is sorted by colour for better orientation. Second fuzzy model was created in the MATLAB – Fuzzy Logic Toolbox. Criteria were divided into three categories to decrease number of rules. Evaluation file were created which determines boundaries for the recommendations and M. file in which inputs are entered and output is gained. Both models are able to provide three recommendations – accept, under consideration or reject. Creation of the models is thoroughly described so even less experienced users can understand the principles how fuzzy models operate.

Both fuzzy models were designed to be more user-friendly and could be used at the company. For both fuzzy models it is possible to create extensions for advanced usage in case that company will require such functions.

For purpose of this diploma thesis consultation with the staff of the company were completed. Information regarding current suppliers, setting up the evaluation criteria and possible future suppliers were collected.

Possible limitations of this work lies in the fact that each target product can bear different technological requirements which not every supplier is capable of. For purpose of this diploma thesis conditions were set up as every supplier were capable to deliver.

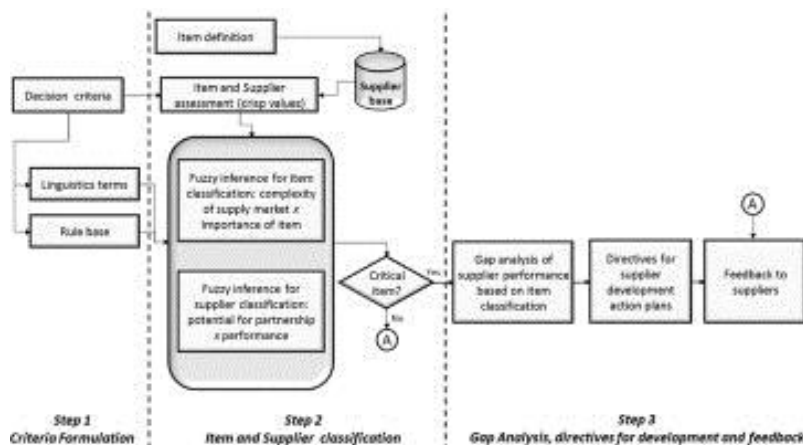
2 THEORETICAL FOUNDATIONS

In this chapter will be discussed theoretical underpinning for this diploma thesis. Supplier evaluation process will be described, followed by brief introduction to fuzzy logic theory. Finally functions which will be used at analytical part of diploma thesis from MS Excel and MATLAB will be presented.

2.1 Evaluation of suppliers

At present time, manufacturing companies rely on suppliers for providing materials and components used in final products. According to Prajogo et. al, (2012) approximately 50-70% of production costs are spent on purchased materials and components. Purchasing decision have significant influence on the cost, quality and delivery of products of the buying company (Talluri and Sarkis, 2002). That is the reason why managing performance of suppliers has become very critical for managing organizations (Schoenherr et al., 2012).

Nevertheless to manage performance of the supplier company first need to perform supplier evaluation. It is quantification process designed to stimulate the decision process inside the evaluating buying company to stimulate a change in behaviour in the evaluated supplying company (Neely et al., 1997). There are number of methods described for supplier evaluation. Osiro et. al, (2014) presented new approach using fuzzy logic. It is based on fuzzy inference combined with simple fuzzy grid method. This method also takes in the consideration type of supplied item.



Picture 1: Fuzzy logic approach to supplier evaluation (source: Osiro et. al, 2014)

2.1.1 Purchase process

Purchase process is set of operations for the purpose of acquiring assets. Such process includes procuring, logistics, acceptance and storing. Essential part of this process is quality check or reclamation of defect goods. According to Lukoszová (2004), there are following categories of purchase process:

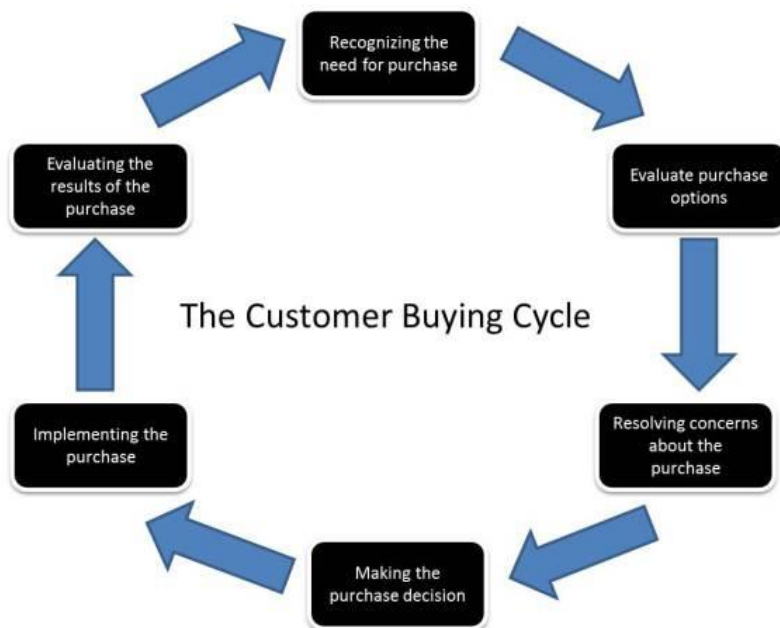
- Redundant purchase (introduced to the economic plan with regular cycle)
- Modified purchase (caused by change in the conditions for example change of demand at the customer side)
- Initial purchase (caused by circumstances leading to storing)

2.1.2 Factors influencing purchase decision

Main factors are price, quality of the component, delivery terms and time. Lukoszová (2004), claims that price is factor number one for the buying company. Price is directly connected with quality and other properties of the component. Second factor is quality since it influence lifetime of the final product. For the buying company is very important price/quality ratio for achieving better production effectiveness. Also quantity of components should be delivered at desired demand because of the storing costs. Delivery terms should be agreed in advance so the supplier can plan production of components and other processes related to the delivery.

2.1.3 Purchase phases

Purchase process can be divided into eight consecutive steps which create a cycle beginning with new purchase (Tomek, 1999).



Picture 2: Purchase process (source: Goodrow, online, 2016)

At the start of the process is need of purchase stimulated by either internal or outside incentive. It is followed by completing the inquiry and evaluating possible suppliers. Taking into account all the technical requirements and factors mentioned earlier we move to the next step of resolving concerns. Now after buying company have selected adequate supplier the purchase decision is made. Components are delivered and final step is evaluation if the delivery is according to the agreed conditions (Tomek, 1999).

2.1.4 Types of suppliers

According to Lukoszová (2004) we can divide suppliers into 3 groups by size:

- Small to medium – hand made products or small serial production, longer production time, higher price nevertheless higher chance to negotiate discounts
- Medium to large – semi-automatic production with lower production time, sufficient quality, better price than smaller suppliers
- Large – fully automatic production, high quantity, lowest production time, lower price can be followed by low quality

Another way of breakdown by Lukoszová (2004) is by attitude towards innovation:

- Conservative type – not seeking innovation, maintaing present relation with the customers

- Innovation type – with their innovation methods are looking to attract new customers with risk of losing present buyers.

2.2 Fuzzy logic (FL)

Concept of Fuzzy logic was presented by Lotfi A. Zadeh, a professor at the University of California at Berkley. He presented it not as control methodology but as way of processing data allowing partial set membership and not only solid membership or non-membership. Professor Zadeh reasoned that people do not require exact numerical information input, and still they are capable of highly adaptive control. In the other words FL is multivalued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Inputs such as rather fast or rather tall can be formulated mathematically and processed by computers, in order to apply a more human-like way of thinking in the programming of computers. The most significant application area of FL has been in control field. Fuzzy control includes fans, complex aircraft engines, helicopter control, missile guidance etc. Fuzzy system performs better when compared with a conventional PID controller. Most famous companies are Mitsubishi, Honda, Sharp, Hitachi, Fuji, General Electric, Siemens (Chennakesava, 2008).

2.2.1 Fuzzy sets

In the classic set theory set is group of elements of any types and basic terms are “set” and “element”. Single element can only represent two states, either it is in the set or not. This can be defined by the function μ_A , which can have values 1 or 0 (Jura, 2003).

$$\mu_A(x) = \begin{cases} 1 & \text{pro } x \in A \\ 0 & \text{pro } x \notin A \end{cases}$$

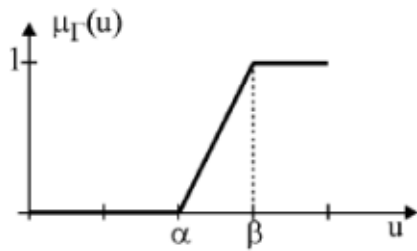
In other words we can assign either solid member or not a member of the set at all to the element. Difference between classic sets and fuzzy set is illustrated at the following picture. Where for the classic set the boundary is clearly visible and for fuzzy one is not.



Picture 3: Clearly visible and fuzzy boundary (source: Jura, 2003)

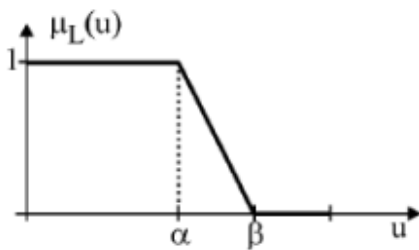
Members function

It is generalised function, expressing affiliation of member to interval (0, 1). Function of affiliation μ_F of fuzzy set is defined as: $\mu_F: U \rightarrow [0, 1]$. It reflects level of affiliation $\mu_F(u) \in [0, 1]$ of element $u \in U$. Members function can have different shape, and it is appropriate to choose most simple function made up in the ideal case from the linear sections. Member degree concerns both input and output functions. Following there are illustrated four of most common and most used functions – Γ , L , Λ , Π (Jura, 2003).



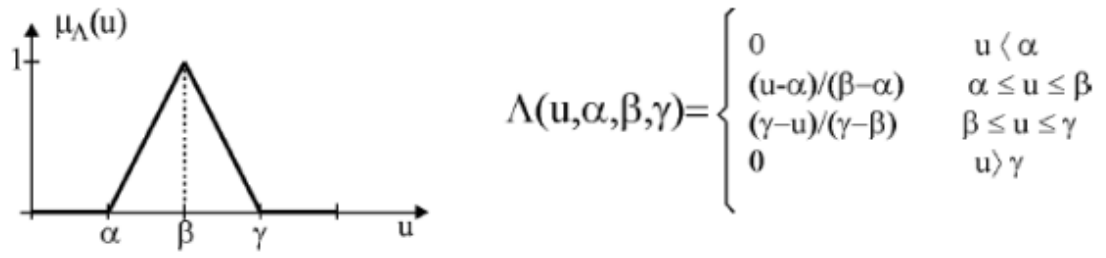
$$\Gamma(u, \alpha, \beta) = \begin{cases} 0 & u < \alpha \\ (u - \alpha) / (\beta - \alpha) & \alpha \leq u \leq \beta \\ 1 & u > \beta \end{cases}$$

Picture 4: Progress and definition of Γ function (source: Jura, 2003)

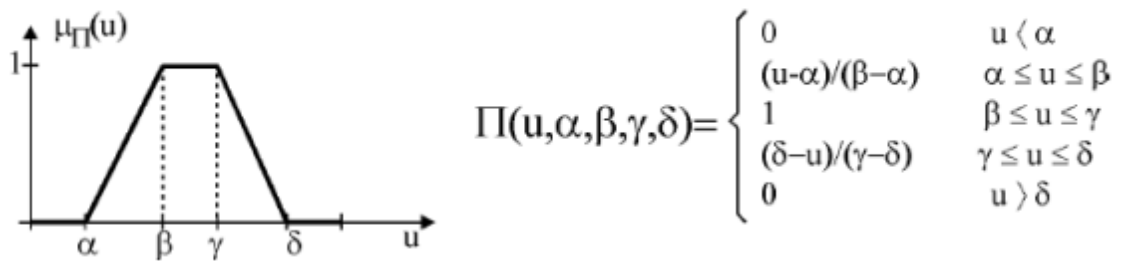


$$L(u, \alpha, \beta) = \begin{cases} 1 & u < \alpha \\ (\beta - u) / (\beta - \alpha) & \alpha \leq u \leq \beta \\ 0 & u > \beta \end{cases}$$

Picture 5: Progress and definition of L function (source: Jura, 2003)



Picture 6: Progress and definition of Λ function (source: Jura, 2003)

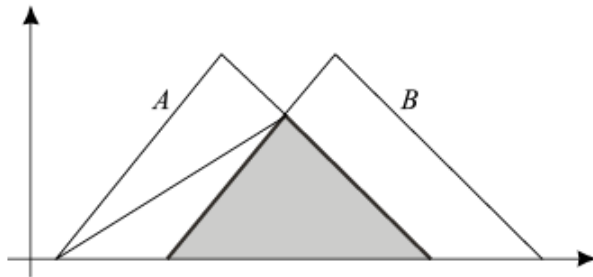


Picture 7: Progress and definition of Π function (source: Jura, 2003)

Operations with fuzzy sets

It is possible to conduct basic operations with fuzzy sets such as intersection, union and complement. The intersection of A and B is defined as following equation:

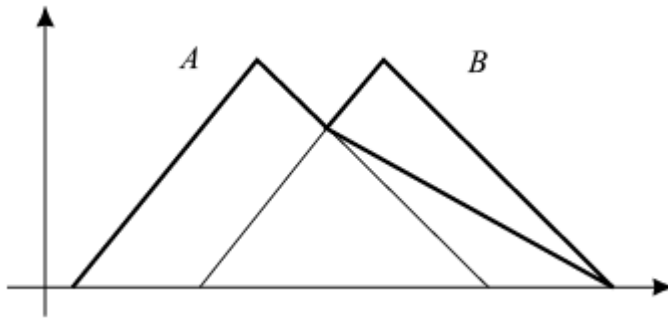
$$(A \cap B)(t) = \min\{A(t), B(t)\} = A(t) \wedge B(t) \text{ for all } t \in X$$



Picture 8: Intersection of two triangular numbers (source: Chennakesava, 2008)

While union of A and B can be defined as:

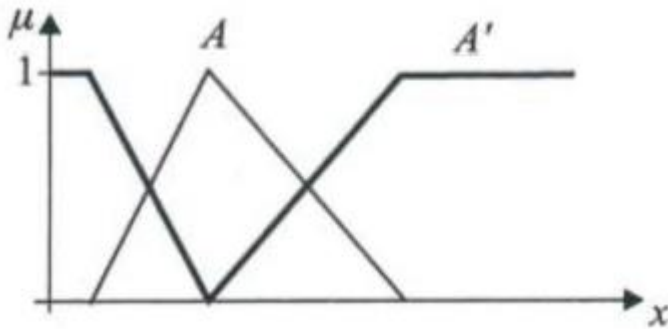
$$(A \cup B)(t) = \max\{A(t), B(t)\} = A(t) \vee B(t) \text{ for all } t \in X$$



Picture 9: Union of two triangular fuzzy numbers (source: Chennakesava, 2008)

The complement of a fuzzy set A is defined as:

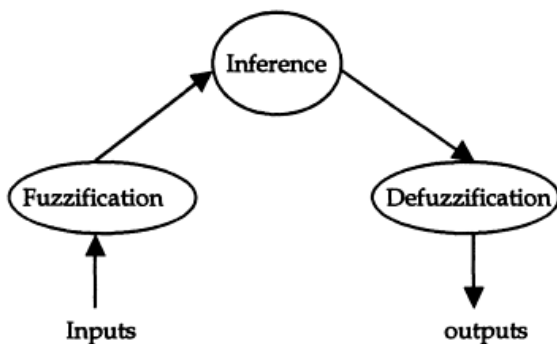
$$(\neg A)(t) = 1 - A(t)$$



Picture 10: Complement of fuzzy sets (source: Dostál, 2015)

Fuzzy process

Fuzzy process is composed from three parts. Process starts with fuzzification, then fuzzy inference and ends with defuzzification.



Picture 11: Fuzzy process (source: Dostál, 2015, edited by author)

In the first part of the fuzzy process we take inputs such as real variables and transform them to linguistic variables. Their values are words or sentences of natural or artificial language. Such represented values are easier for humans to understand.

During the phase of fuzzy inference transformation matrix is constructed which transforms data into numbers. After that rules are defined on the linguistic level based on which the whole system is working. Such rules are: $\langle IF \rangle$, $\langle with\ weight \rangle$ and $\langle THEN \rangle$ (Dostál, 2012).

In the last part called defuzzification retransforming matrix is constructed to transform results from fuzzy inference. Therefore fuzzy output values are transformed to the linguistic form (Dostál, 2012).

2.3 MS Excel

To create fuzzy model in the MS Excel we need to construct 4 tables. First one includes description of transformation matrix. For each criteria exists several options listed which can value acquire. Following example is constructed for the decision-making process on purchase of tablet.

Table 1: Transformation matrix – description (source: authors work)

Input	1	2	3	4	5	6
	weight	display size	CPU core	RAM	HDD	battery
1	<0,4 kg	7"	1	<1 GB	4-8 GB	4 hrs.
2	0,4 - 0,9 kg	7"-8"	2	1 GB	16 GB	5 hrs.
3	>0,9 kg	9"-10"	3	2 GB	32 GB	6 hrs.
4		10.1"	4	4 GB	64GB	6-10 hrs.
5		>11"			128 GB	>10 hrs.

Second table is same transformation matrix but with attributes from previous matrix transformed to the numeric values. These numeric values represents priorities which were set up by user to meet his needs. In this case maximum value is 10 and minimum is 0.

Table 2: Transformation matrix – criterias with weights (source: authors work)

Input	1	2	3	4	5	6
	weight	display size	CPU core	RAM	HDD	battery
1	10	5	0	0	0	1
2	8	7	4	4	5	3
3	5	9	6	7	7	5
4		10	10	10	8	9
5		2			10	10

As you can see at this example table we are targeting tablet with low weight, medium display size, high performance and long lasting. After we have entered our priorities we can continue with entering input data.

Enter tablet parameters		
1.	Weight	<0,4 kg ▼
2.	Display size	10.1" ▼
3.	Number of CPU cores	4 ▼
4.	RAM	4 GB ▼
5.	HDD	128 GB ▼
6.	Battery	>10 hrs. ▼
7.	Multidotykový displej	yes ▼
8.	Rozlišení displeje	2048 x 1536 ▼
9.	GPS	yes ▼
10.	USB	yes ▼
Recommendation recommend to buy Result 100%		

Picture 12: Entry table for tablet parameters (source: authors work)

As we can see this are top priorities for the user since we have achieved 100% and state matrix for that choice is following:

Table 3: State matrix (source: authors work)

Input	1	2	3	4	5	6
	weight	display size	CPU core	RAM	HDD	battery
1	1	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4		1	1	1	0	0
5		0			1	1

As we have mentioned before. At the column of parameters we can see only one 1 value rest have to be 0. That represents which option we have selected. If we change entry parameters that change will reflect at the state matrix.

Enter tablet parameters		
1.	Weight	0,4 - 0,9 kg ▼
2.	Display size	9"-10" ▼
3.	Number of CPU cores	2 ▼
4.	RAM	1 GB ▼
5.	HDD	16 GB ▼
6.	Battery	4 hrs. ▼
7.	Multidotykový displej	yes ▼
8.	Rozlišení displeje	2048 x 1536 ▼
9.	GPS	yes ▼
10.	USB	yes ▼
Recommendation recommend to buy Result 80%		

Picture 13: Entry table for tablet parameters - changed (source: authors work)

We can observe how state matrix has changed with this amendments in the entry table:

Table 4: State matrix – changed (source: authors work)

Input	1	2	3	4	5	6
	weight	display size	CPU core	RAM	HDD	battery
1	0	0	0	0	0	1
2	1	0	1	1	1	0
3	0	1	0	0	0	0
4		0	0	0	0	0
5		0			0	0

By the scalar sum from transformation matrix and state matrix is calculated precise number value. From that value we have to deduct sum of individual values, divide it by difference of maximum and minimum of sum and multiply by number 100. By that procedure we can achieve result from 0 – 100%.

Last table which we have to create is retransformation matrix. Based on that matrix we will get output in the linguistic form.

Table 5: Retransformation matrix (source: authors work)

Result [%]	Recommendation
0-50	Not recommended to buy
50-79	Evaluate other possibilities
80-100	Recommended to buy

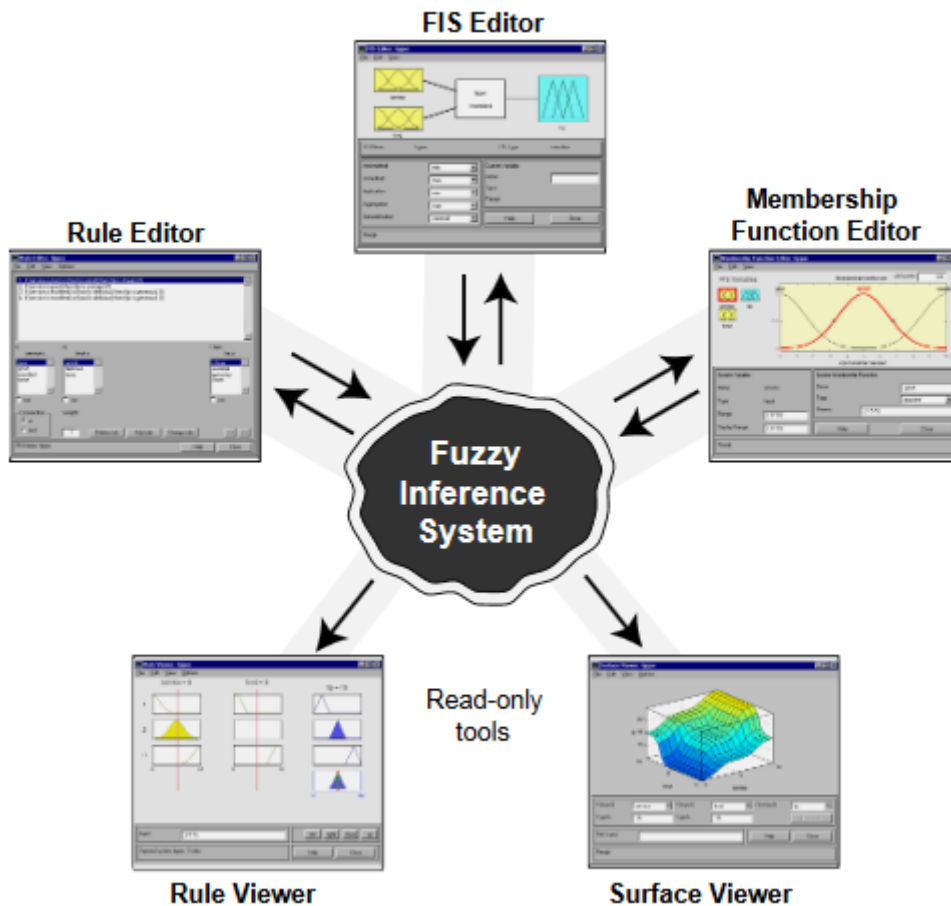
2.4 MATLAB

MATLAB is integrated environment which serves for scientific and technical calculations, simple and more complex modelling, simulations, data analysis, signals processing, measurement, proposing control and communication systems. Therefore nowadays it is one of the basics for technical simulations in the field of science, research or education. MATLAB is consists of five primary parts:

- Calculating core – contains algorithms for working with matrixes of real and complex numbers.
- Graphic subsystem – serves to graphically display results, graphs, two-dimensional and three-dimensional and their animations
- Open architecture – contains built-in functions, allows also to create new functions, when MATLAB is whole programming language
- Working tools - allows to create applications, contains commands conditioned branches, cycles.
- Toolboxes – library of functions, which expands usage in the given field, contains pre worked special functions with options and modifications (MATLAB, 2016).

2.4.1 Fuzzy Logic Toolbox

Fuzzy model in the MATLAB will be created by Fuzzy Logic Toolbox, which expands basic functions of MATLAB with support of fuzzy logic. It is composed from 5 basic graphic instruments such as FIS Editor (Fuzzy inference system editor), MF editor (Membership function editor), Rule editor, Rule viewer and Surface viewer. This tools allows to create, edit and preview fuzzy inference system (MATLAB, 2016).



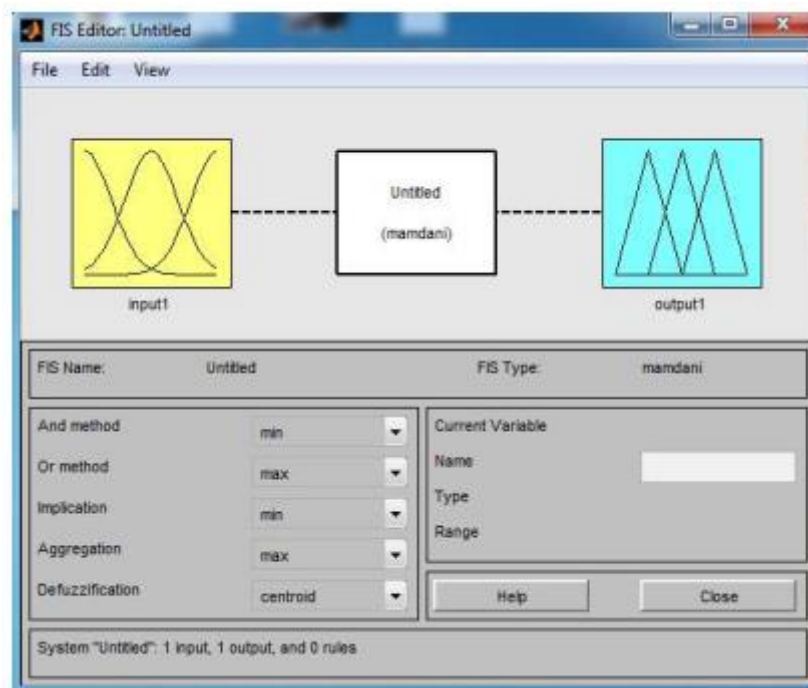
Picture 14: Main tools of fuzzy inference system (source: MATLAB, 2016, online)

In the following subchapter this tools will be briefly presented.

2.4.1.1 FIS Editor

FIS Editor (Fuzzy Inference System) tool allows to define basic parameters of fuzzy system. In other words, input and output values, defuzzification methods, way of implication and aggregation and setting rules for system behaviour.

Editor is started by entering word “fuzzy” in the Command Window in the MATLAB. We will work with Mamdani system type with single input and output values. Other values are added through bookmark “Edit/Add Variable”. Based on which value are required to add we choose from “Input” or “Output” (Dostál, 2008).



Picture 15: FIS Editor (source: Dostál, 2008)

Afterwards at the “Edit” bookmark it is possible to add another membership function through button “Add MFs” or to delete them one by one “Remove Selected MF” or all of them by “Remove ALL MFs” (Dostál, 2008).

Such resulting fuzzy system created at FIS Editor can be saved as structure to the “Workspace” or as a file with .fis format. With such created and saved fuzzy system we can work later in MATLAB or at simulation extension Simulink through “fuzzy logic controller” (MATLAB, 2016).

2.4.2 MF Editor

MF Editor allows to view and edit all membership functions. It is possible to define different types and shapes of membership functions. For example:

- Trimf (triangle \wedge function)
- Trampf (Π function, possible Γ or L function)
- Smooth functions (Gaussmf, Gbellmf etc.)

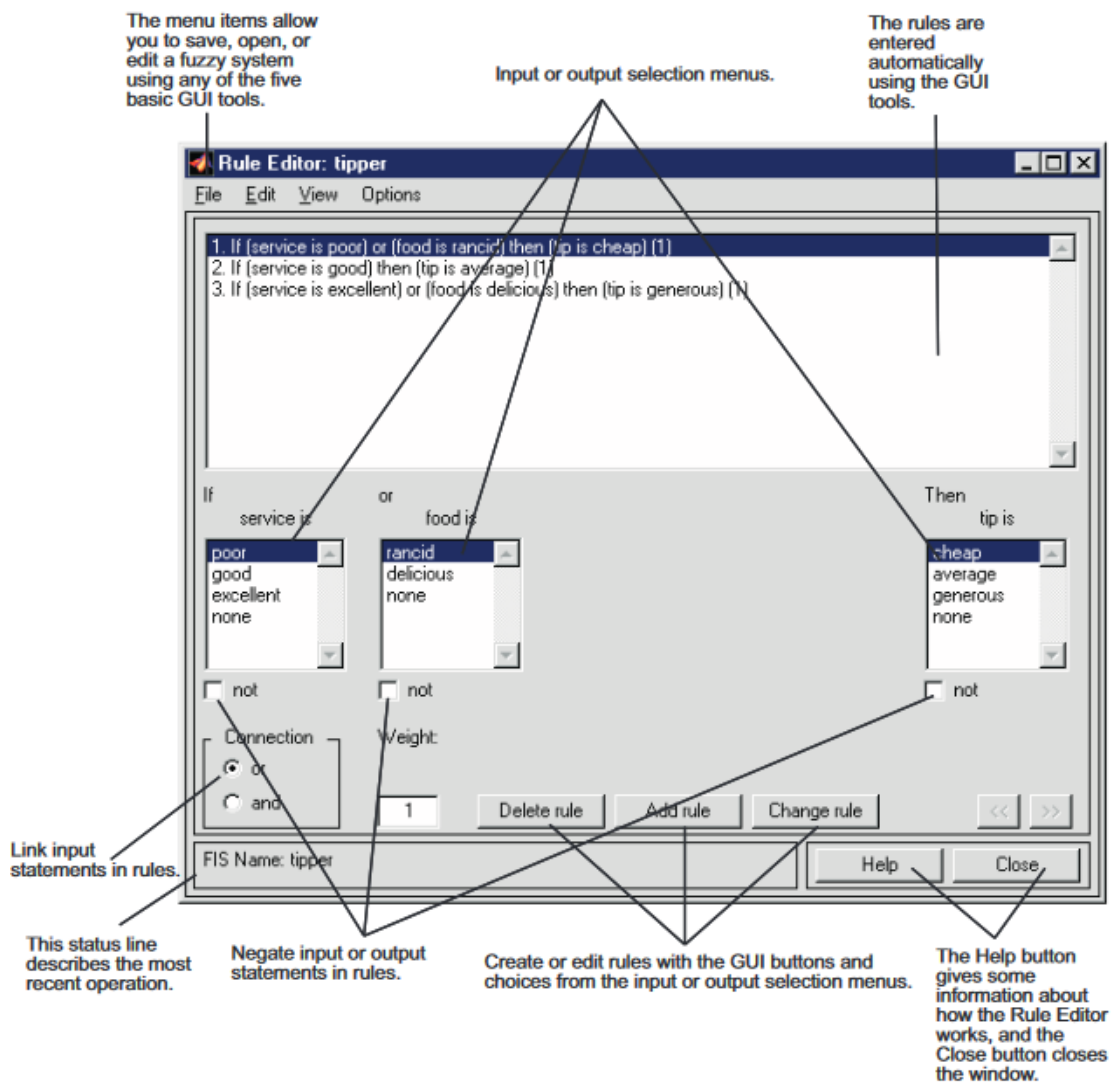


Picture 16: MF Editor (source: Dostál, 2008)

At the bottom part it is possible to set up name, range and number of functions for every input and output values (MATLAB, 2016).

2.4.3 Rule Editor

As from the name of this tool is clear Rule Editor allows to add, edit and remove fuzzy rules. This rules determines dependence between input and output values. Upper part is list of rules with bottom part displays values for each rule. Rules are connected by logic operators AND or OR. While creating such rules values are chosen, their interrelationship and depending value of output value. It is also possible to set up weight of the rule.

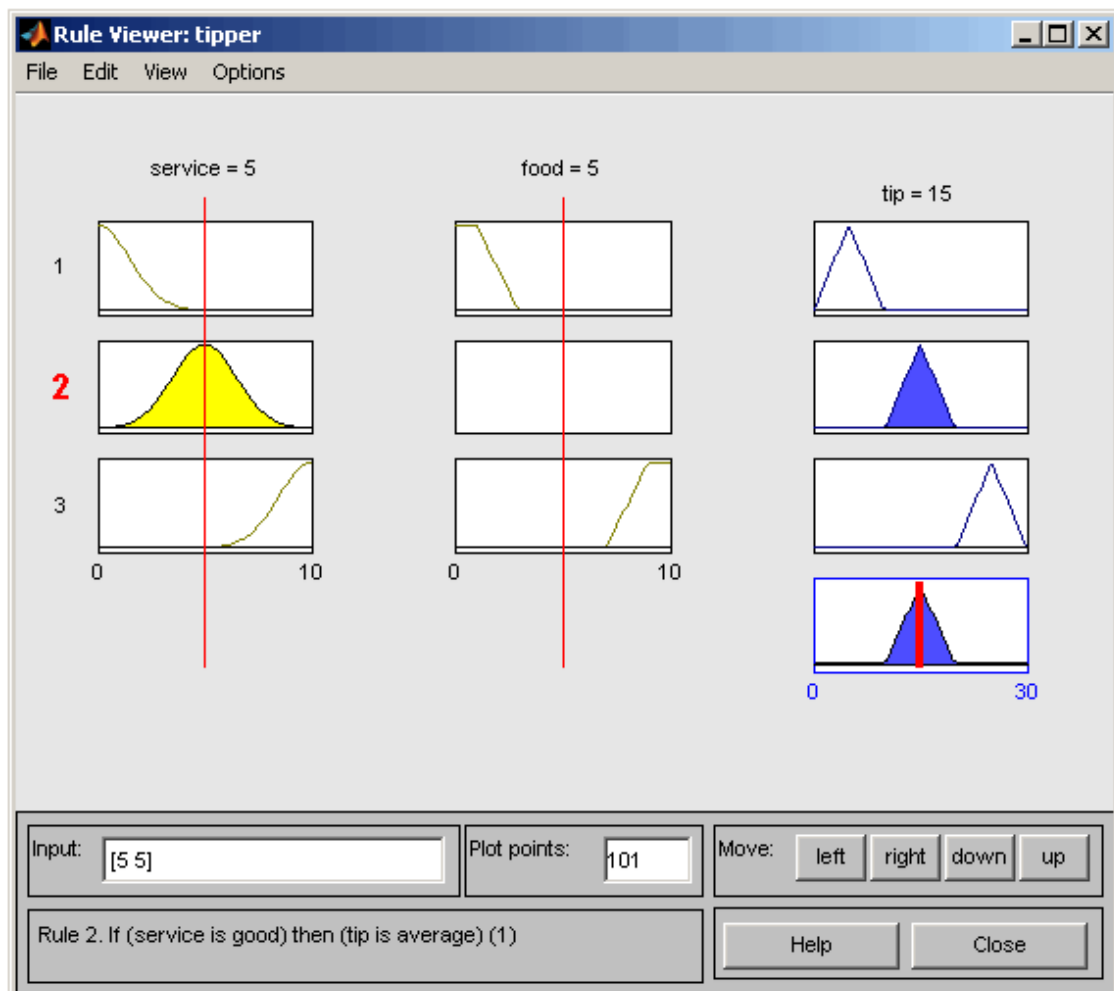


Picture 17: Rule Editor (source: MATLAB, 2016)

2.4.4 Rule Viewer

Through Rule Viewer it is possible to review detailed behaviour of fuzzy inference system. Not only you can diagnosis the behaviour of the system but also it is possible to examine influence of changing input values (MATLAB, 2016).

At the picture below is preview of Rule Viewer. We can see single figure with 10 plots displayed in it. Each rule is a row of plots and each column is variable. Rule numbers are displayed on the left of each row. If we click on the rule number the rule will be displayed at the “status line”. At the left bottom corner it is possible to add precise input values with which we are able to manipulate by moving red vertical lines. After each change the new calculation will be done. Result from new calculation is visible at the output column.

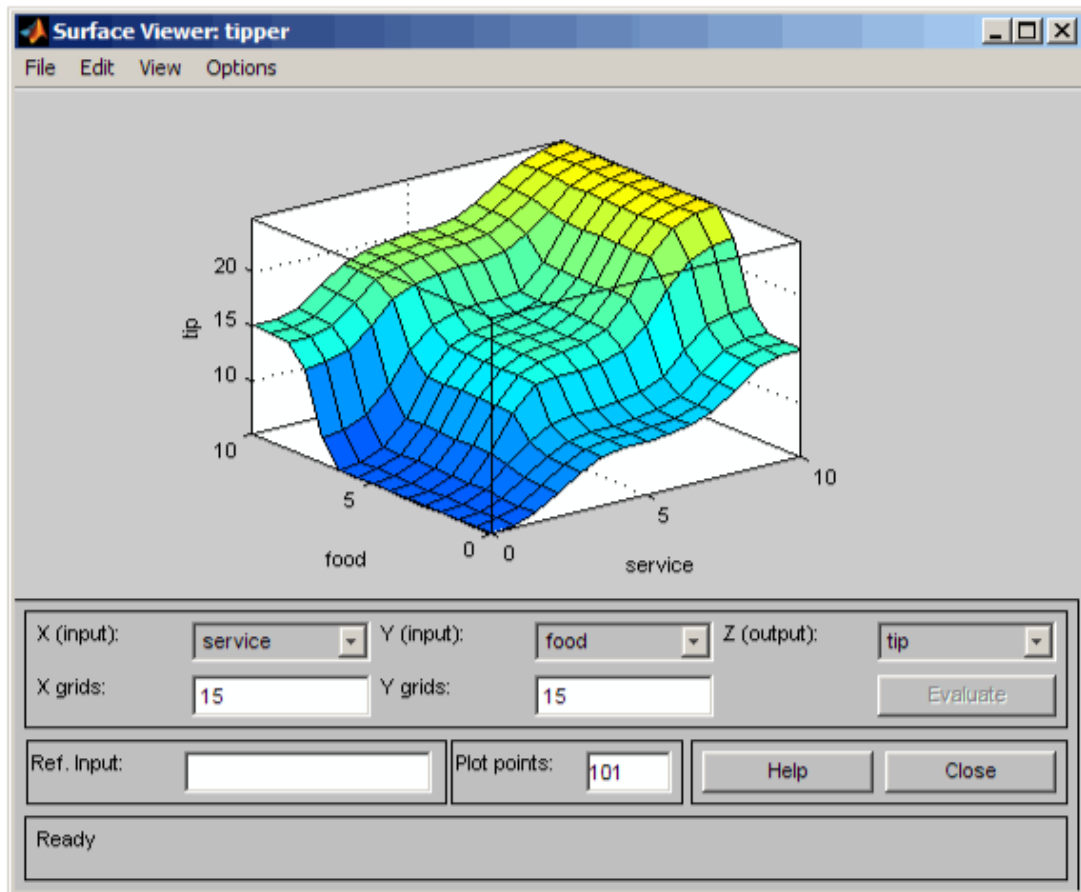


Picture 18: Rule Viewer (source: MATLAB, 2016)

2.4.5 Surface Viewer

Surface Viewer allow to display three dimension graphic view of output values in the dependence on the input values by defined rules in the Rule Editor. Surface Viewer can display function of single input value after that result is displayed as surface or two values then the result is displayed by three dimension graph (MATLAB, 2016).

Example of Surface Viewer window is displayed on the picture below. There we can see fuzzy system with two inputs and one output value. In case of systems with two inputs and one output value there are no difficulties with their graphic representation. It is getting more difficult with higher number of input values. For that reason there is pop-up menu under the graph by which it is possible to select only two inputs and one output. By mouse we can grab and move one of the axis which allows us to see graph from different angle (MATLAB, 2016).



Picture 19: Surface Viewer (source: MATLAB, 2016)

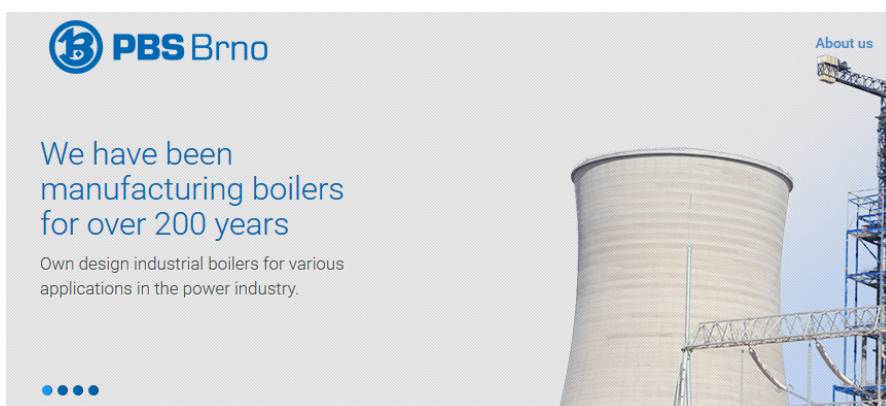
3 PROBLEM ANALYSIS AND CURRENT SITUATION

Third chapter of this diploma thesis is dealing with problem analysis and current situation of the company. This chapter is divided into two parts. First starting with brief introduction of the PBS Brno company, followed by short explanation about their product and situation on the market. Second part will focus on present system of supplier evaluation and suppliers will be briefly presented. Chapter will be finished by explanation of each factor selected for the supplier evaluation in the fuzzy system.

3.1 První brněnská strojírna, a.s.

První brněnská strojírna, a.s. is Original Equipment Manufacturer (OEM) company which provides complex services in the construction of power and heat stations. Company controls own knowhow of boilers for different types of fuel among others company is active on the field of biofuel boilers (PBS Brno, 2016).

PBS Brno has long tradition since year 1814. Company finished its research and development of biomass boilers at year 2004. At year 2004 was realised first project of this kind, Wicker and followed by Pforzheim in 2005 both at Germany (Appendix 1). Later company realised projects locally in Czech republic at Kutná Hora and Křnov also both for biomass boiler. World competition on the segment of steam boilers are intense with companies present such as Weissman, Babcock Wanson or Bosch. Therefore to succeed company need to gain some competitive advantage. Since PBS Brno is not manufacturing any part of the final product they fully rely on their suppliers.



Picture 20: PBS Brno (source: PBS Brno, 2016)

3.1.1 Current method of suppliers evaluation

At the present time company does not own any system for supplier evaluation. Each time company is sending demand form to the suppliers. Therefore PBS Brno would benefit from fuzzy model for suppliers evaluation. Company have long lasting relationship with most of the suppliers. In this diploma thesis we will evaluate seven suppliers for fans.



Picture 21: Industrial boiler fan - example (source: GlobalMarket Group, 2016)

3.1.2 List of present suppliers

In this subchapter suppliers are briefly presented. In the Appendix 2 is list of the suppliers with which PBS Brno cooperates.

Howden

Howden is worldwide corporation with long history. Started at year 1854 when James Howden set up his own consulting engineering business in Scotland.

Nowadays company's sales, engineering, R&D and project management departments are based in Næstved, Denmark, in Växjö, Sweden and in Ebnet, Germany. Using modern design techniques and computer aided design brings high quality. R&D department are developing both mechanical and aerodynamic segments to satisfy customer needs and to improve performance. Manufacturing facilities are located at Weihai, China. Company possess ISO 9001:2008 accreditation for quality assurance procedures, environmental standards are certified by ISO 14001:2004 and health and safety programme OHSAS 18001:2008 (Howden Group, 2016).



Picture 22: Howden company logo (source: Howden, 2016)

Piller industrial fans

Piller is company located at the Moringen, Germany. Founded in year 1909, by Anton Piller. Nowadays it is medium sized company. Nevertheless with subsidiaries in the USA, China, Singapore and Shanghai. Focusing not only at the blowers but also at waste water treatment, general plant engineering, chemical industry, industrial furnace, power plants and petrochemical industries. Piller counts among the international technology leaders for high-performance blowers and compressors. Quality assurance is according to the DIN EN ISO 9001 certificate. Furthermore Piller has numerous approvals and qualifications such as approval for welding of military installations according to DIN 2303Q2 IBK 2, approval as welding company according to DIN EN 3834-2 and AD2000 HP0 as well as approval compliant with GOST-EAC.

Provides customer-specific solutions that are optimally configured to the different application and material. More than 80% of products are custom made. Putting emphasize on the additional service before and after the purchase.



Picture 23: Piller company logo (source: Piller, 2016)

Reitz Ventilatoren

Reitz is one of the world's leading providers of top-quality industrial fans with manufacturing plants in Germany, Switzerland, China and India. Fans with power ratings of up to 10 000 kW operated in Europe are produced in Germany. Company was found in year 1948 and since now business has remained family-owned. Nowadays company consists of about 400 employees. Company possess ISO 9001:2008 accreditation for quality assurance procedures, environmental standards are certified by ISO 14001:2009 and health and safety programme OHSAS 18001:2007 and more (Reitz, 2016).



Picture 24: Reitz Ventilatoren company logo (source: Reitz, 2016)

Rotamill

Rotamill was founded in year 1974 at Germany by engineer Bernhard Plath after World War II. Original of Rotamill was a special techniques of grinding sulphur. Nowadays Rotamill consists of about 90 employees nevertheless sales volume are more than 20 million Euro. Since 2008 Vigor Holding owns the Rotamill group. Products of Rotamill can be found in various brances such as dedusting, suction processes, ventilation, cooling or drying. Company possess ISO 9001:2008 accreditation for quality assurance procedures.



Picture 25: Rotamill company logo (source: Rotamill, 2016)

Sirocco

Sirocco company was founded in 1888 by machine trader William Beney together with Robert Child. First premises was at Vienna nowadays head office and factory is still in Vienna but production has moved to the Poland. Except industrial fans Sirocco is also manufacturing tunnel equipment, heat exchangers and dust extraction technics. Sirocco also offers service and maintenance. Nowadays Sirocco consists of about 130 employees. Company possess ISO 9001:2008 accreditation for quality assurance procedures (Sirocco, 2016).



Picture 26: Sirocco company logo (source: Sirocco, 2016)

TLT-Turbo GmbH

TLT-Turbo GmbH evolved from Dinglerwerke AG, Benno Schilde AG and the fan division of Babcock Wilcox AG Oberhausen. Following the foundation of Dinglerwerke AG in year 1827 and takeover of the fan division of Babcock Wilcox AG, Turbo-Lufttechnik GmbH was established in Zweibrücken in July 1970. Company manufactures technology-driven industrial fans and ventilation systems. Nowadays TLT-Turbo GmbH consists of about 360 employees. Company possesses ISO 9001:2008 accreditation for quality assurance procedures, environmental standards are certified by ISO 14001:2009 and health and safety programme OHSAS 18001:2007 and more (TLT-Turbo GmbH, 2016).



TLT-Turbo GmbH

Picture 27: TLT-Turbo GmbH company logo (source: TLT-Turbo GmbH, 2016)

Edel Vent

Edel Vent founded in year 2004 at Slovakia. It is quite new company nevertheless it is already supplied more than 100 high-performance industrial fans on the European market. Company is medium-sized with less than 50 employees. Edel Vent is also focusing on the complex supply of suction and dedusting systems. Company possesses ISO 9001:2008 accreditation for quality assurance procedures (Edel Vent, 2016).



Picture 28: Edel Vent company logo (source: Edel Vent, 2016)

3.1.3 Suppliers evaluation criteria

Selection of appropriate criteria are based on the general attributes therefore decision-making model can be used repeatedly. Nevertheless that topic was discussed with company staff who are dealing with offers evaluation on the daily basis. For supplier evaluation three main categories were specified:

- Price + Finance (product price, payment terms, price negotiation)
- Delivery terms (delivery time, delivery costs, delivery reliability)
- Quality + Innovation (product quality, technological capability, supplier willingness)

Price + Finance

Price of the product by itself is main factor for every company nevertheless other criteria are also important.

Product price

As mentioned before it is main factor. Nevertheless it should not be only decisive factor. It is more appropriate to evaluate price/quality ratio for the supplier evaluation. Product price will be compared between all suppliers which are being evaluated and will be described as low, medium, high or very high.

Payment terms

Payment terms are also significant factor since some suppliers will require payment in advance others when the goods are delivered. Due date of payment is important for the company since it can keep their financial assets longer if due date of payment is longer. Payment terms will be compared between all suppliers which are being evaluated and will be described as very high, high, medium, low or very low.

Price negotiation

Price negotiation factor will be dealing with possibility of possible price discount. It is goal of the company to try achieve some discount of the price. Price negotiation will be compared between all suppliers which are being evaluated and will be described as very high, high, medium, low or very low.

Delivery terms

In some cases more important factor than price. It is possible that price of the product will be low but either delivery time will be unacceptable or transport costs will adjust price higher than other suppliers.

Delivery time

We start with delivery time as first criteria from delivery terms set. In some cases company is willing to wait for the delivery and in some urgent cases delivery time can be top priority criteria for the evaluation. In this diploma thesis will be this criteria will be set on the average scale. Delivery time will be compared between all suppliers which are being evaluated and will be described as low, medium, high or very high.

Delivery costs

Delivery costs can have significant influence on the final price of the product. In consideration should be taken distance from where the product is being dispatched. Also possible ways of transport which supplier is willing to secure. Delivery costs will be compared between all suppliers which are being evaluated and will be described as low, medium, high or very high.

Delivery reliability

Delivery reliability is summary of smaller criteria. Factors such as dispatch of the product will be on time, transport of product will be without damage, delivery costs will be as promised etc. This criteria can be perceived as less important however such small aspects can dissuade company to aware this inconvenience and choose another supplier next time. Delivery reliability will be compared between all suppliers which are being evaluated and will be described as very high, high, medium or low.

Quality + Innovation

All the suppliers claims that their products are of high quality. However there are still slight differences. This criteria was discussed with the expert from the company based on the previous experience.

Quality of the product

Quality of the product is of the main criteria since all the others factors are directly dependent on the quality. Certification of the suppliers will be taken into consideration also. With higher product is expected less complaint later on. Product quality will be compared between all suppliers which are being evaluated and will be described as very high, high, medium or low.

Technological capabilities

In some cases of more powerful fans not all suppliers are capable to manufacture desired product. For purpose of this diploma thesis is taken into consideration such product which all suppliers are capable to deliver. Technological capabilities will be compared between all suppliers which are being evaluated and will be described as very high, high, medium or low.

Supplier willingness

In supplier willingness criteria we can include overall communication with supplier, possible technical adaptations based on the requirement from the company and afterward service and complaints. Supplier willingness will be compared between all suppliers which are being evaluated and will be described as very high, high, medium, low or very low.

4 PROPOSALS AND CONTRIBUTION OF SUGGESTED SOLUTIONS

In the third chapter of this diploma thesis fuzzy models are created and described. Models are created in MS Excel and MATLAB. Afterwards earlier mentioned suppliers are evaluated based on the criteria mentioned in the previous chapter. Finally proposals will be presented.

4.1 Fuzzy model in MS Excel

First fuzzy model will be created in the MS Excel (with addition of the Virtual Basic Language). With software is installed on every personal computer at the company and staff know how to use it. Fuzzy model will be created to be user friendly and in the future cases easy to edit in the case of need.

4.1.1 Fuzzification

For evaluation process, it is important to create description and transformation matrix. In which there are between four and five linguistic values describing criteria which can be seen in table 7. For each criteria there will be assigned weight. In table 8 we can see such weights between 100 (maximum) and 0 (minimum). For each criteria different weights are set.

The rating scale of supplier evaluation has been set as follows:

- 〈75 to 100〉 Accept
- 〈50 to 74〉 Under Consideration
- 〈0 to 49〉 Reject

To be more user-friendly conditional formatting has been used, it is displayed in table 8. Green colour represents “Accept”, orange colour “Under Consideration” and red colour is for “Reject”. Bottom two lines of the table 7 are minimum values added up (125) and maximum values (850). These two values will be used for the scalar product formation.

Table 6: Explanations of abbreviations used in MS Excel (source: own work)

Abbreviation	Explanation
PP	Product Price
PT	Payment Terms
PN	Price Negotiation
DT	Delivery Time
DC	Delivery Costs
DR	Delivery Reliability
PQ	Product Quality
TC	Technological Capabilities
SW	Supplier Willingness

Table 7: Description matrix (source: own work)

PRICE+FINANCE				DELIVERY TERMS			QUALITY+INNOVATION		
DM	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	low	very high	very high	low	low	very high	very high	very high	very high
2	medium	high	high	medium	medium	high	high	high	high
3	high	medium	medium	high	high	medium	medium	medium	medium
4	very high	low	low	very high	very high	low	low	low	low
5		very low	very low						very low

Table 8: Transformation matrix (source: own work)

TM	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	100	90	100	100	90	90	100	90	90
2	80	70	85	75	75	70	80	75	75
3	50	45	75	20	50	50	65	65	65
4	5	10	50	0	20	20	0	25	50
5		5	25						25
125	5	5	25	0	20	20	0	25	25
850	100	90	100	100	90	90	100	90	90

4.1.2 Rule construction

For each company the scalar product is calculated. Afterwards condition rules are set up for linguistic rating as mentioned earlier. In table 9 all scalar products are displayed:

Table 9: Scalar products (source: own work)

HOWDEN	=WHEN(A38=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B33:J37)-\$A\$19)/(\$A\$20-\$A\$19);-1)
PILLER	=WHEN(A47=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B42:J46)-\$A\$19)/(\$A\$20-\$A\$19);-1)
REITZ	=WHEN(A56=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B51:J55)-\$A\$19)/(\$A\$20-\$A\$19);-1)
ROTAMILL	=WHEN(A65=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B60:J64)-\$A\$19)/(\$A\$20-\$A\$19);-1)
SIROCCO	=WHEN(A74=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B69:J73)-\$A\$19)/(\$A\$20-\$A\$19);-1)
TLT-TURBO	=WHEN(A83=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B78:J82)-\$A\$19)/(\$A\$20-\$A\$19);-1)
EDEL VENT	=WHEN(A92=1;100*(SCALAR. PRODUCT(\$B\$14:\$J\$18;B87:J91)-\$A\$19)/(\$A\$20-\$A\$19);-1)

Following figure illustrates conditional rule in MS Excel:

=WHEN(A38=1;WHEN(O19<49;"REJECT";WHEN(19<74;"UNDER CONSIDERATION";"ACCEPT"));"ERROR")

Expressed in the words, if number at the cell "A38" is 1 (it means there is no error – it will be explained later) then, according to the result recommendation will be:

- Reject
 - If the value is between 0 and 49
- Under Consideration
 - If the value is between 0 and 74 (included 74).
- Accept
 - If the value is between 75 and 100

It is possible to move boundaries later on if company staff will recognize it as appropriate. Also values for evaluation of supplier are possible to amend later through the table of respective supplier.

4.1.3 Evaluation of supplier

As an example is evaluated company called Howden, illustrated in table 10. As can be observed from the table it is most expensive supplier with relatively high delivery time and delivery costs. On the other hand product quality is high and it is absolute top in the technological capabilities and supplier willingness. However due to low results in the finance sector this supplier was found as unacceptable.

Table 10: Howden supplier evaluation (source:own work)

HOWDEN									
S1	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	0	1	0	1	1
2	0	0	0	0	0	0	1	0	0
3	0	0	0	1	1	0	0	0	0
4	1	0	0	0	0	0	0	0	0
5		1	1						0
1	1	1	1	1	1	1	1	1	1

List with all supplier evaluations can be found in Appendix 3.

4.1.4 Avoiding errors during input

Since it is easy to make mistake during filling in the values for each supplier secure measurement was carried out.

As it was mentioned earlier during explanation of the conditional rules, if value at the cell “A38” is not 1 – the error statement will occur (for each supplier the cell is different).

Table 11: Error in supplier rating (source: own work)

HOWDEN				
S1	PP	PT	PN	DT
1	0	0	0	0
2	1	0	0	0
3	0	0	0	1
4	1	0	0	0
5		1	1	
2	2	1	1	1

Also such error is transferred to the table with all the supplier ratings. Recommendation will be set up as “ERROR”.

Table 12 - Error in the supplier ratings (source: own work)

Supplier	Points	Recommendation
HOWDEN	-1	ERROR
PILLER	77	ACCEPT
REITZ	70	UNDER CONSIDERATION
ROTAMILL	59	UNDER CONSIDERATION
SIROCCO	55	UNDER CONSIDERATION
TLT-TURBO	62	UNDER CONSIDERATION
EDEL VENT	79	ACCEPT

Such presented formatting is set up for all evaluations.

4.1.5 Defuzzification

Defuzzification process was performed for the supplier evaluation. Recommendation can acquire state “Accept”, “Under consideration” or “Reject”. In case of error during input it also can acquire “Error” state as was presented earlier.

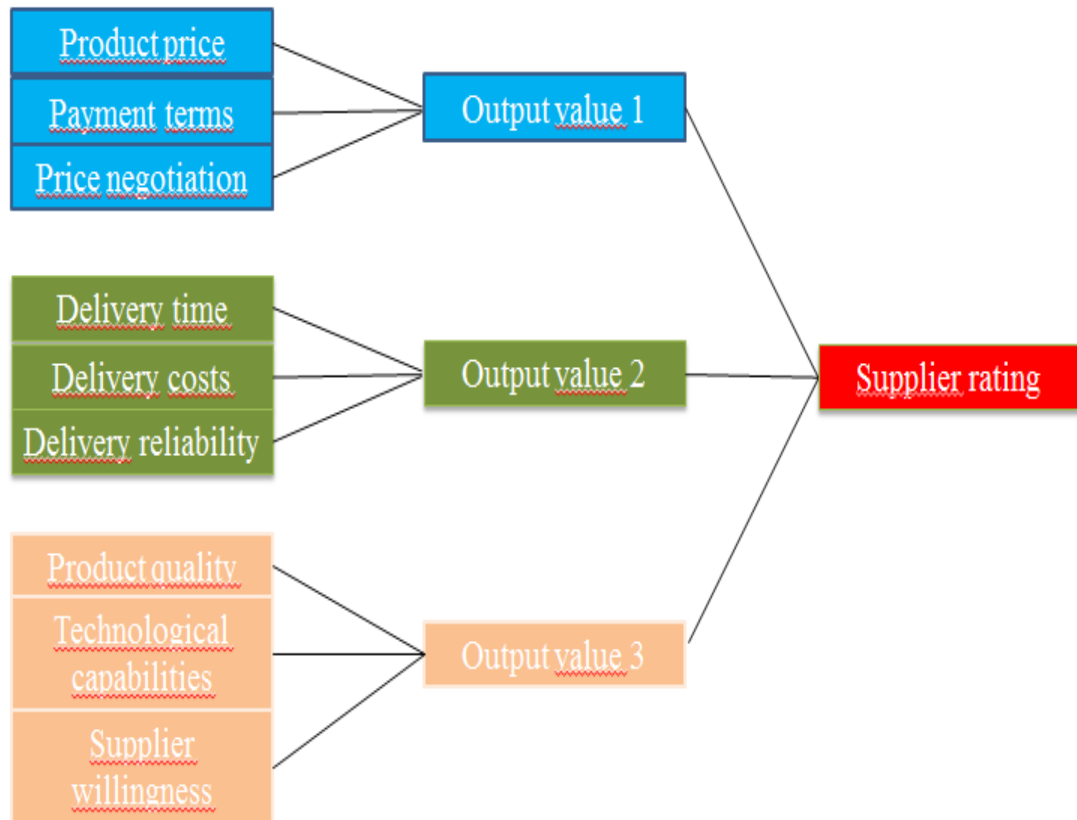
Table 13: Supplier rating (source: own work)

Supplier	Points	Recommendation
HOWDEN	46	REJECT
PILLER	77	ACCEPT
REITZ	70	UNDER CONSIDERATION
ROTAMILL	59	UNDER CONSIDERATION
SIROCCO	55	UNDER CONSIDERATION
TLT-TURBO	62	UNDER CONSIDERATION
EDEL VENT	79	ACCEPT

Later results will be discussed and compared with results from the MATLAB.

4.2 Fuzzy model in MATLAB

To create fuzzy model for supplier evaluation we will use same inputs as were used for the MS Excel fuzzy model however procedure is kind of different. For better understanding following diagram was created:



Picture 29: Diagram for MATLAB procedure (source: own work)

The evaluation process consists of four main parts:

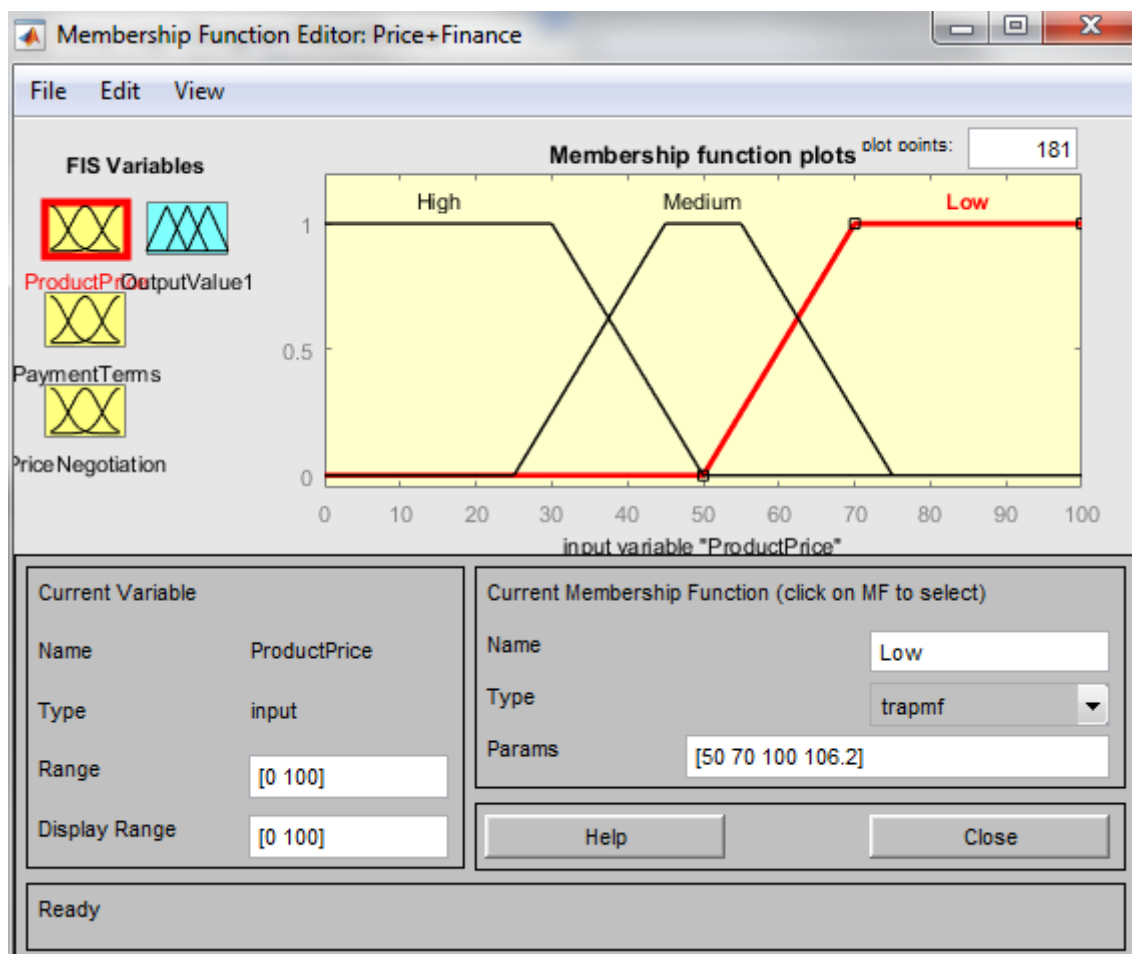
- Price + Finance
- Delivery terms
- Quality + Innovation
- Final

4.2.1 Fuzzification for Price + Finance

Factor of Price + Finance include three inputs:

- Product price (high, medium, low)
- Payment terms (low, medium, high)
- Price negotiation (low, medium, high)

Picture below represents Output 1, it was gained after applying all 27 rules.



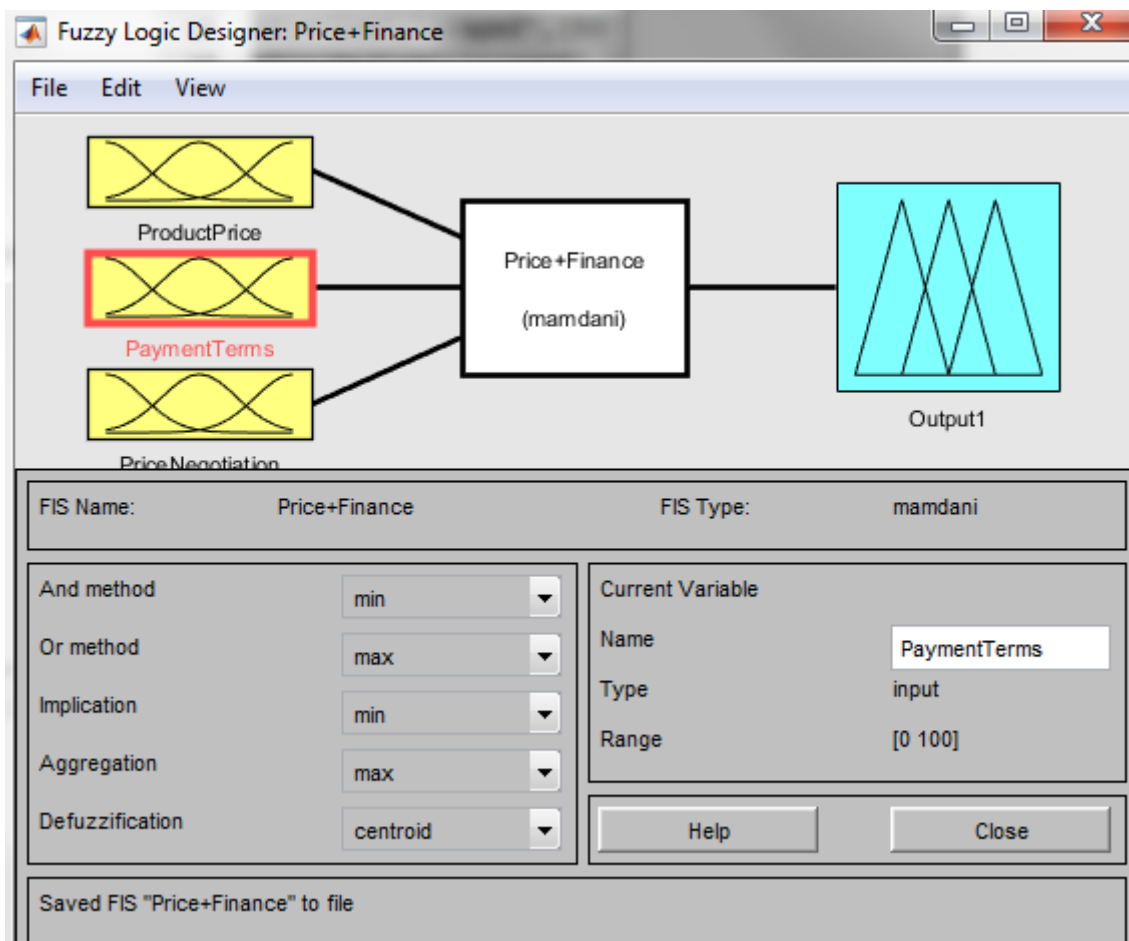
Picture 30: MF Editor for Price + Finance (source: own work)

Range scale of supplier in the MATLAB is slightly different from which was used at MS Excel. Following table will display the range:

Table 14: Output 1 for Price+Finance (source: own work)

Variable	Range
Poor	0-50
Average	25-75
Excellent	50-100

Following picture represents trapmf trapezoidal shaped membership functions. As it was mentioned earlier and seen from the chart, the function has a value between 0 and 1. By other words it also characterises how much it belongs to a certain fuzzy set. If value is 1, then it belongs to the fuzzy set, on the other hand if the value is 0 then it does not belong to the fuzzy set.



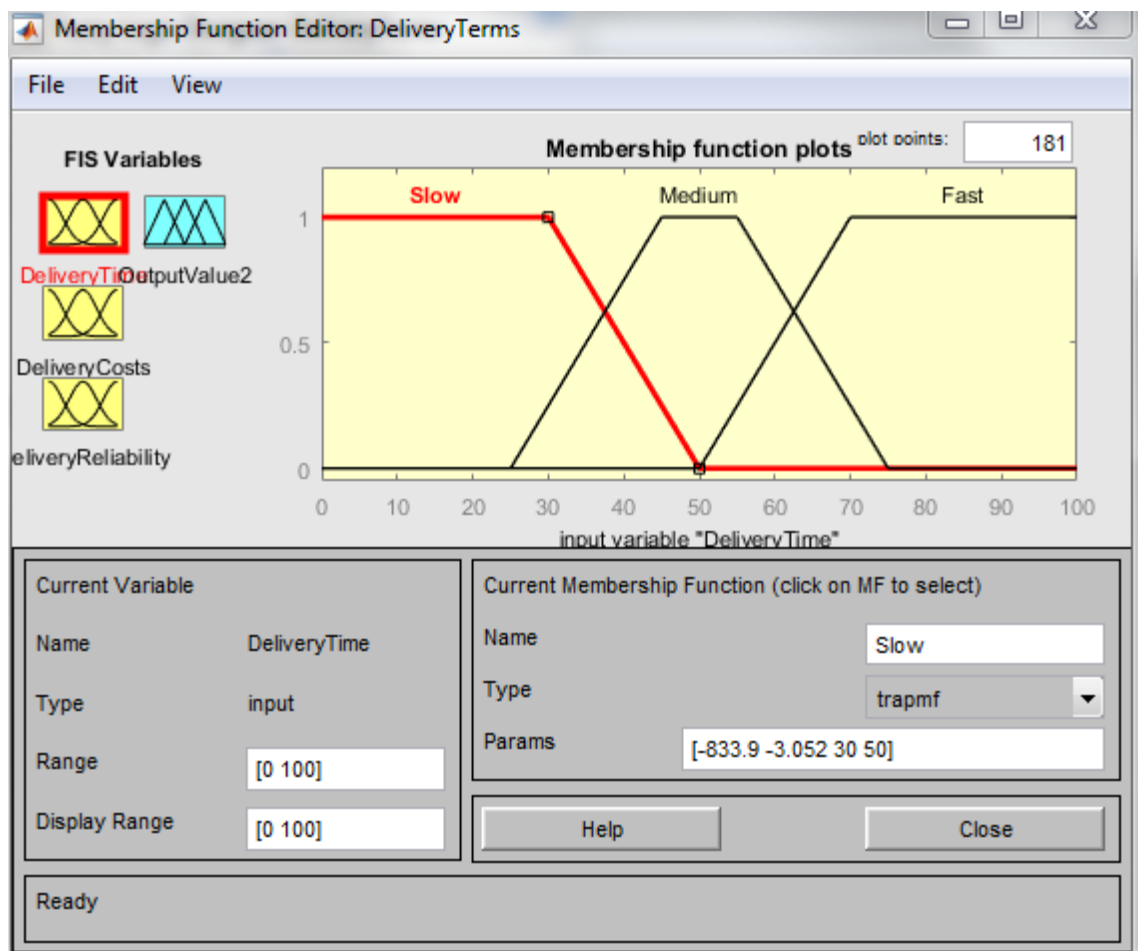
Picture 31: Membership functions for Price+Finance (source: own work)

4.2.2 Fuzzification for Delivery Terms

This part includes three inputs:

- Delivery time (slow, medium, fast)
- Delivery costs (high, medium, low)
- Delivery reliability (low, medium, high)

Following picture displays MF Editor for Delivery Terms.



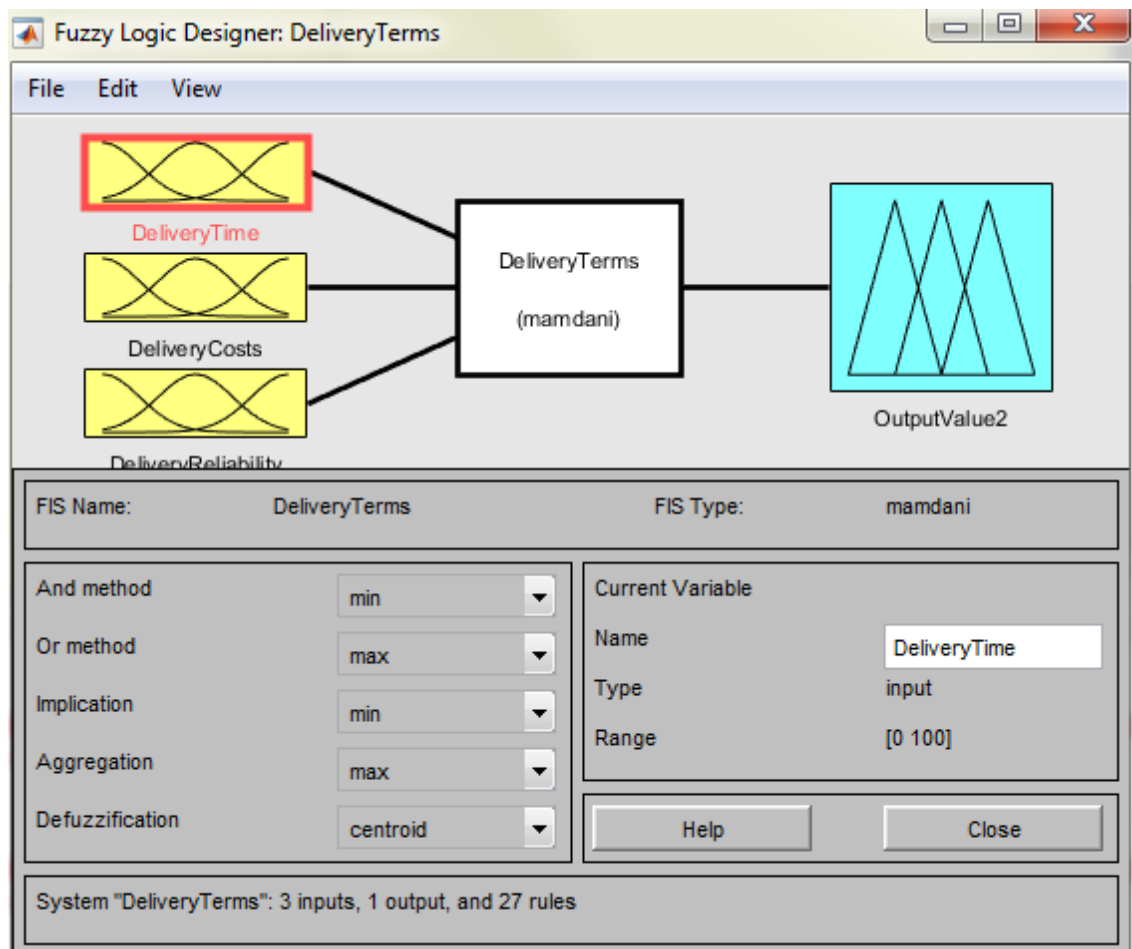
Picture 32: MF Editor for Delivery Terms (source: own work)

For Delivery terms range of values are displayed at the following table:

Table 15: Output range for Delivery terms (source: own work)

Variable	Range
Low	0-50
Medium	25-75
High	50-100

Trampf membership function for the DeliveryTerms are displayed below:



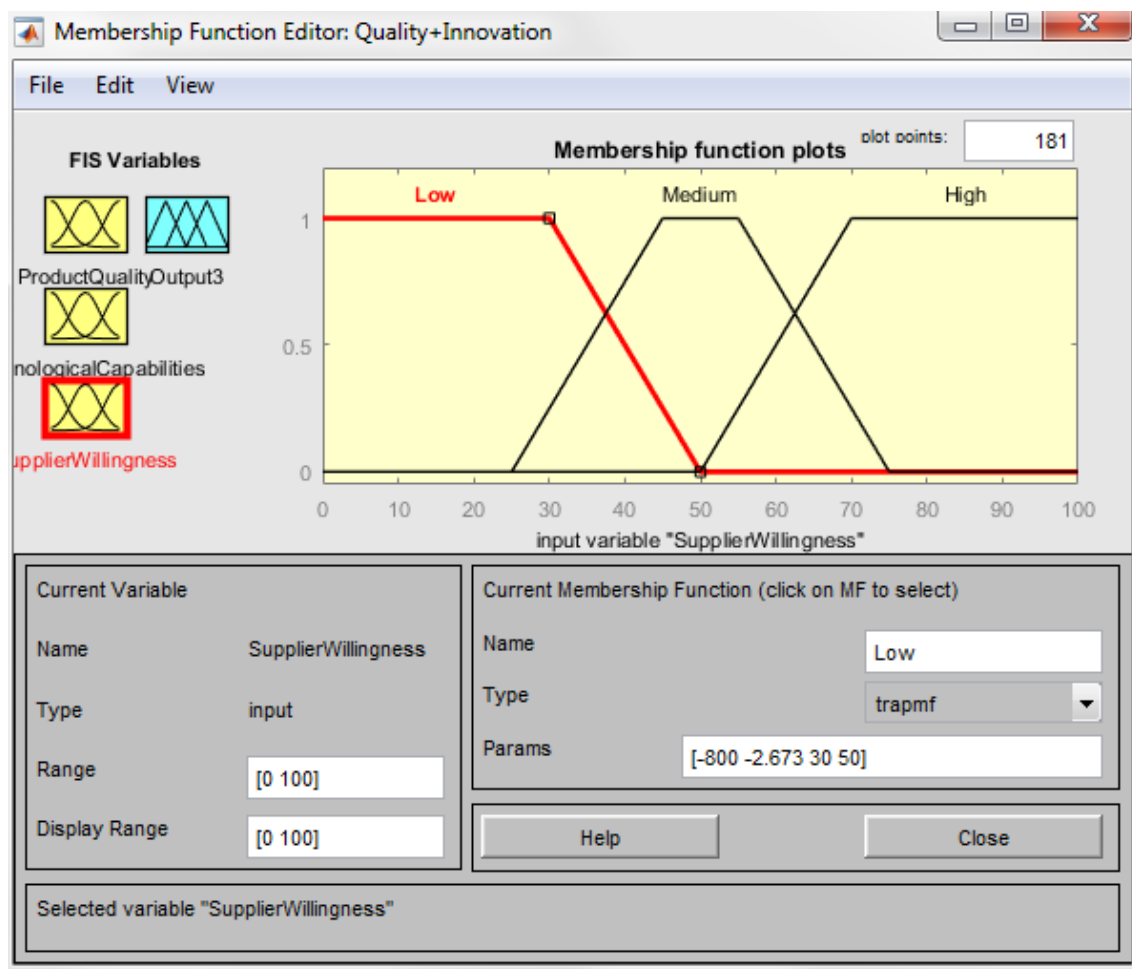
Picture 33: Membership functions for Delivery terms (source: own work)

4.2.3 Fuzzification for Quality + Innovation

This part includes three inputs:

- Product quality (low, medium, high)
- Technological capabilities (low, medium, high)
- Supplier willingness (low, medium, high)

Picture below represents MF Editor for Quality + Innovation.



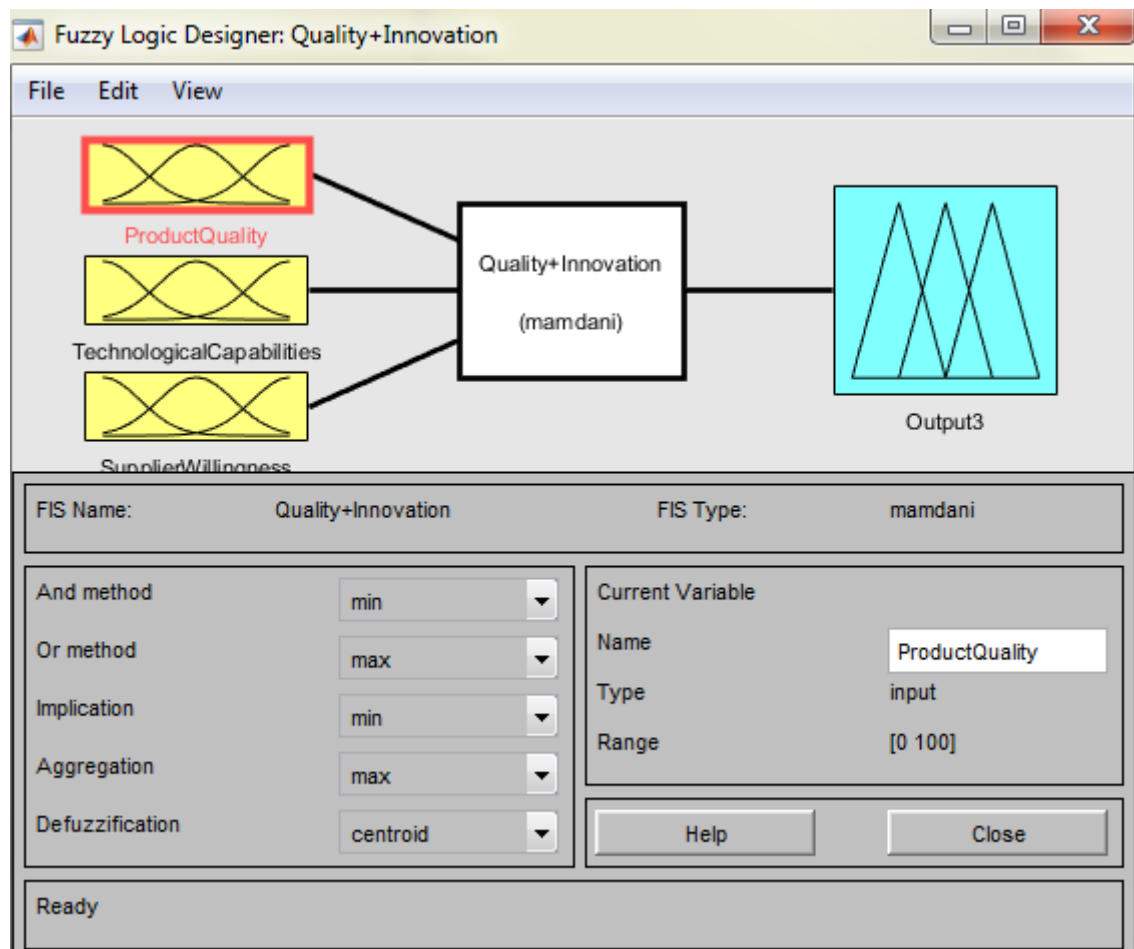
Picture 34: MF Editor for Quality + Innovation (source: own work)

Table 16 represents range for Output 3:

Table 16: Output 3 for Quality + Innovation (source: own work)

Variable	Range
Low	0-50
Medium	25-75
High	50-100

And for the Output 3 membership function is displayed below:

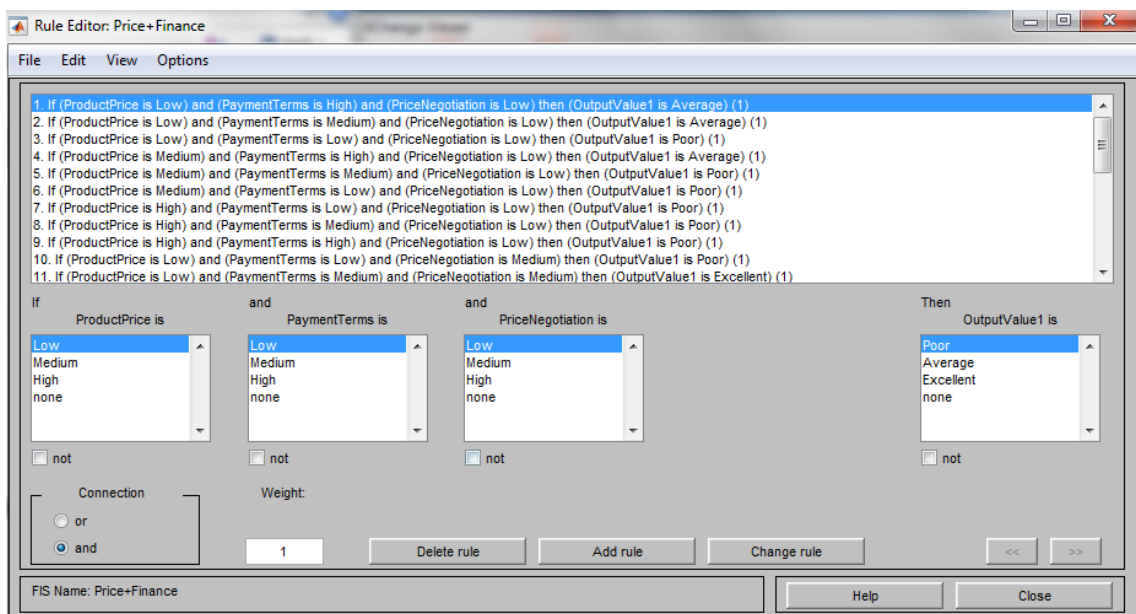


Picture 35: Membership functions for Quality + Innovation (source: own work)

4.2.4 Fuzzy rule construction

To achieve value calculations it is required to set up the rules in the fuzzy model. Inputs were split into three categories (Price + Finance, Delivery terms and Quality + Innovation) therefore number of rules has decreased. During creation of rules logic operator “AND” were used. Every category has 3 inputs each with 3 attributes that means 27 rules for each category. Total number of rules is 81.

It is possible to edit, add and deletes rules in the Rule Editor as displayed at the following picture:



Picture 36: Rule Editor for Product + Price (source: own work)

Rules also can be created by entering them to the FIS file under label “Rules”. Such approach was used during creating fuzzy model for this diploma thesis. Following picture illustrates record of this method. Displayed is part of the rules for the Price + Finance category. First three numbers represents value of the chosen inputs and number after the coma represents value of the output. In the other word 1 means “poor”, 2 means “average” and 3 means “excellent”.

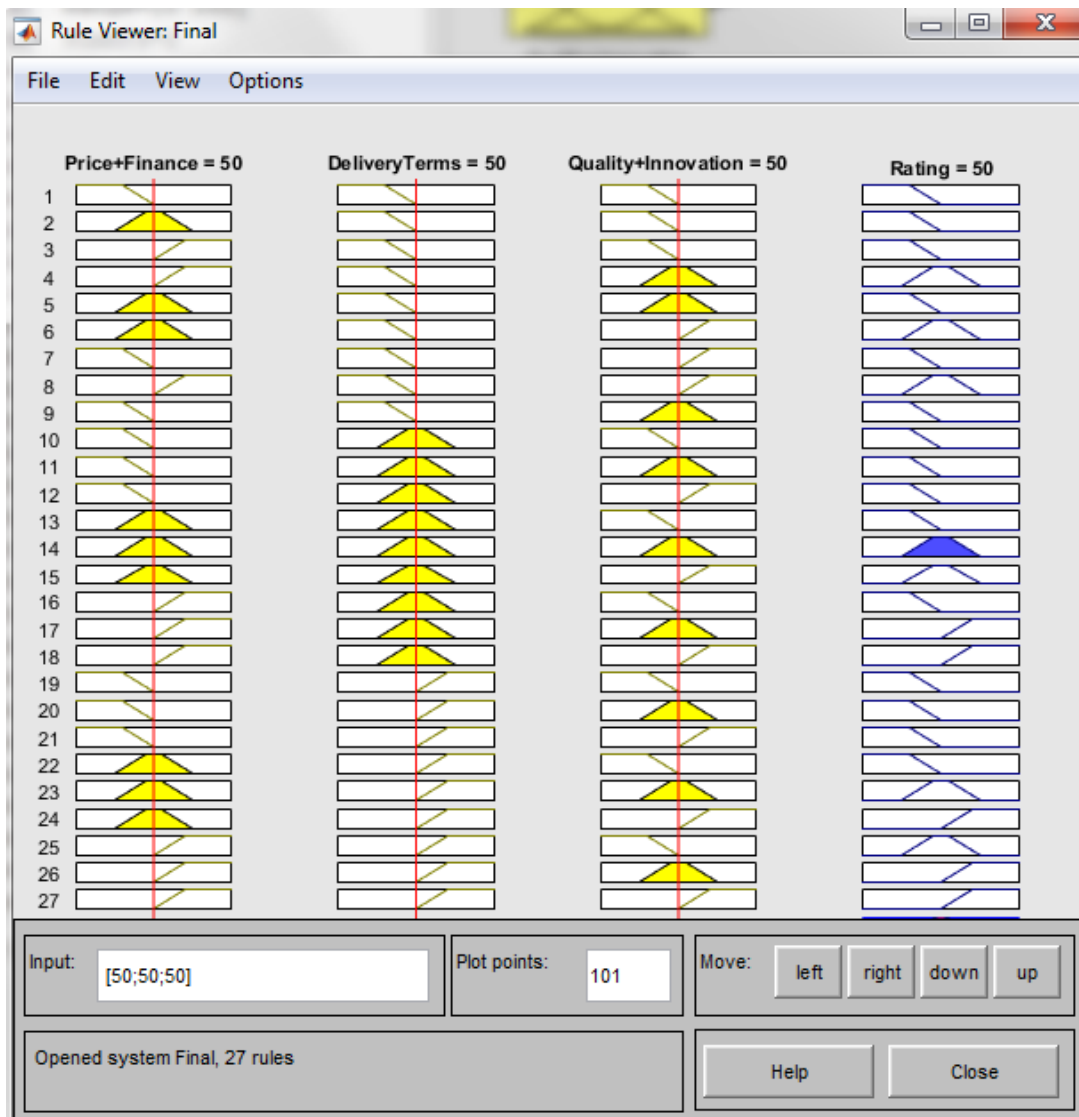
```

[Rules]
1 3 1, 2 (1) : 1
1 2 1, 2 (1) : 1
1 1 1, 1 (1) : 1
2 3 1, 2 (1) : 1
2 2 1, 1 (1) : 1
2 1 1, 1 (1) : 1
3 1 1, 1 (1) : 1
3 2 1, 1 (1) : 1
3 3 1, 1 (1) : 1
1 1 2, 1 (1) : 1
1 2 2, 3 (1) : 1
1 3 2, 3 (1) : 1
2 1 2, 1 (1) : 1

```

Picture 37: Rules construction in the FIS file (source: own work)

After rules are constructed it is possible to view them in the Rule Viewer, which is displayed on the picture 37.



Picture 38: Rule Viewer for Final (source: own work)

4.2.5 Evaluation process

Supplier evaluation process in MATLAB is started can be started by launching M-file which will be discussed below:

```
%%
clear all
BP = readfis('Price+Finance.fis');
UdajBP = input('Zadejte vstupní údaje ve tvaru [ProductPrice; PaymentTerms; PriceNegotiation]: ');
VyhBP = evalfis(UdajBP, BP);

BQ = readfis('DeliveryTerms.fis');
UdajBQ = input('Zadejte vstupní údaje ve tvaru [DeliveryTime; DeliveryCosts; DeliveryReliability]: ');
VyhBQ = evalfis(UdajBQ, BQ);

BS = readfis('Quality+Innovation.fis');
UdajBS = input('Zadejte vstupní údaje ve tvaru [ProductQuality; TechnologicalCapabilities; SupplierWillingness]: ');
VyhBS = evalfis(UdajBS, BS);

BF = readfis('Final.fis');
UdajBF(1) = VyhBP;
UdajBF(2) = VyhBQ;
UdajBF(3) = VyhBS;
VyhBF = evalfis(UdajBF, BF);
UdajBF
VyhBF
if VyhBF<=35 'Reject'
elseif VyhBF<65 'Under consideration'
else 'Accept'
end
%fuzzy(BF)
%mfedit(BF)
%ruleedit(BF)
%surfview(BF)
%ruleview(BF)
```

Picture 39: M-file (source: own work)

From this picture we can see clearly structure of the evaluation process.



Picture 40: Start of M-file (source: own work)

After start of the process user is asked to fill in the values for each criteria. Range is from 0 (lowest) to 100 (best).

```

>> SF

```

```

>> SF

```

```

Zadejte vstupní údaje ve tvaru [ProductPrice; PaymentTerms; PriceNegotiation]: [20; 20; 15]

```

```

Zadejte vstupní údaje ve tvaru [DeliveryTime; DeliveryCosts; DeliveryReliability]: [75; 70; 90]

```

```

Zadejte vstupní údaje ve tvaru [ProductQuality; TechnologicalCapabilities; SupplierWillingness]: [80; 100; 95]

```

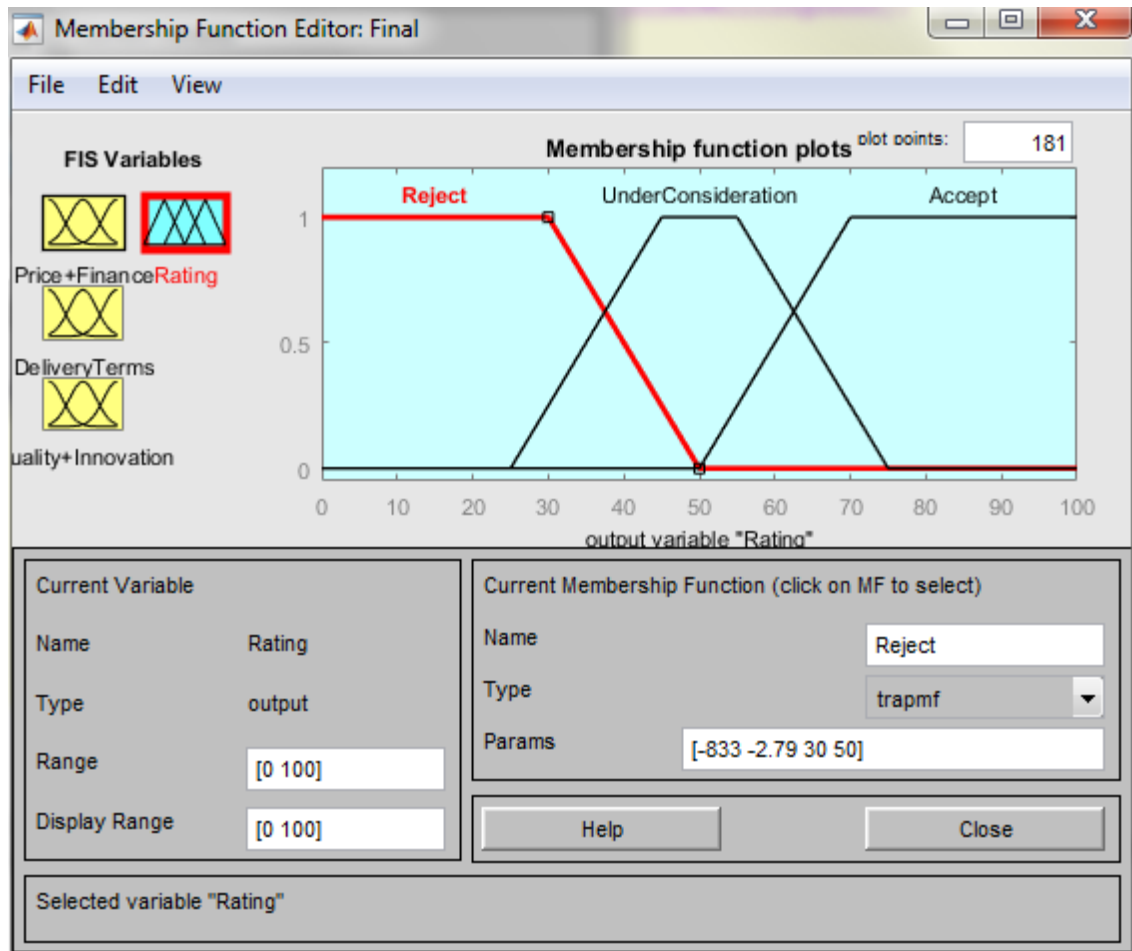
Picture 41: Command Window - start of the M-file (source: own work)

We have entered values for the company Howden. Afterwards we get the results for entered values. Based on the range entered in the Final .fis file:

Table 17: Range for supplier evaluation (source: own work)

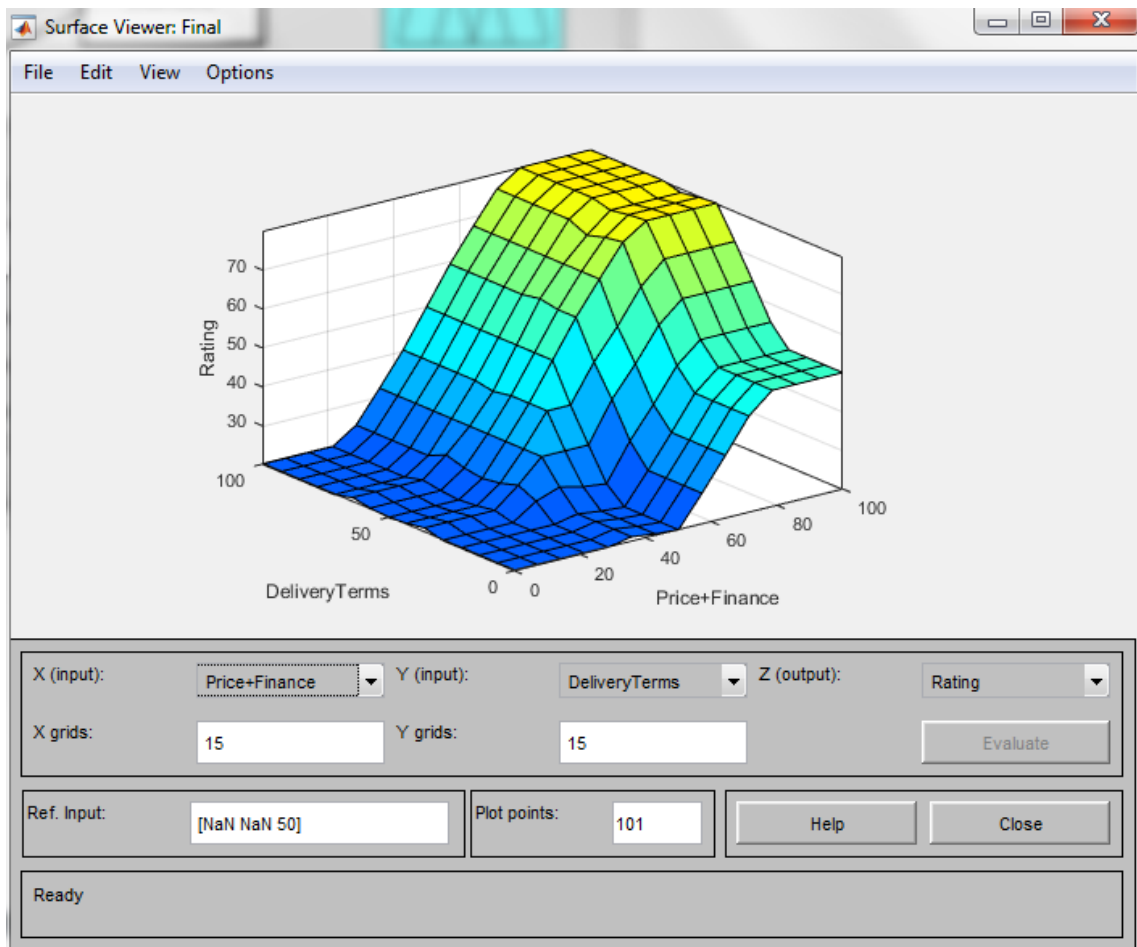
Fuzzy	Variable	Range
1	Reject	0 - 50
2	Under Consideration	25 - 75
3	Excellent	50 - 100

Following picture displays MF Editor for Final:



Picture 42: MF Editor Final (source: own work)

As can be seen on the picture 42 function can possess value 0 or 1 as was explained earlier. Followed by picture 43 with surface viewer where dark blue area defines the surface the reject, light blue specifies for under consideration and yellow surface represents accept decision.



Picture 43: Surface viewer Final (source: own work)

5 RESULTS

5.1 MS Excel results

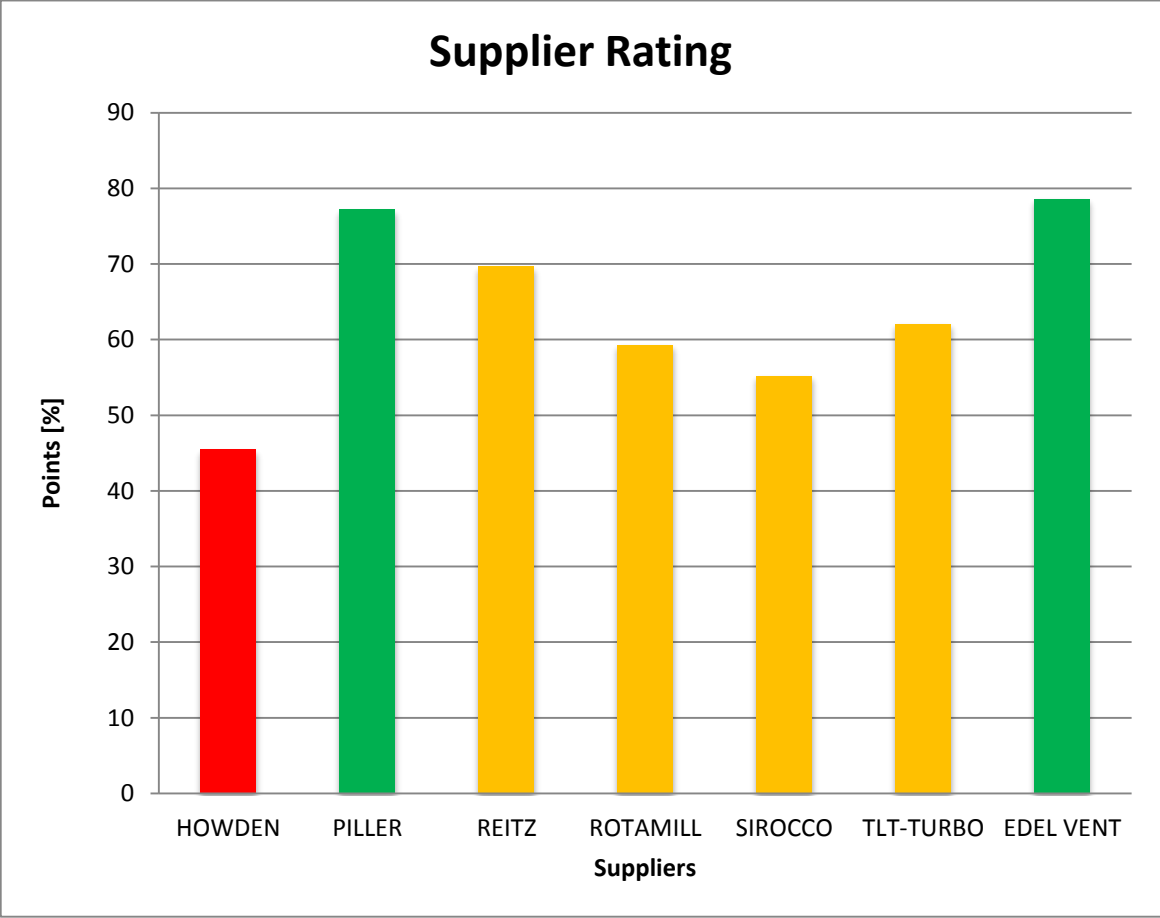
Evaluation results processed by the MS Excel are displayed in the table 18. Highest score achieved company Edel Vent (79) followed by Piller (77). Both companies achieved “Accept” recommendation. Rest of the companies were evaluated with “Under Consideration” recommendation except Howden (46) which finished with recommendation “Reject”.

Table 18: MS Excel result (source: own work)

Supplier	Points	Recommendation
HOWDEN	46	REJECT
PILLER	77	ACCEPT
REITZ	70	UNDER CONSIDERATION
ROTAMILL	59	UNDER CONSIDERATION
SIROCCO	55	UNDER CONSIDERATION
TLT-TURBO	62	UNDER CONSIDERATION
EDEL VENT	79	ACCEPT

Table 18 shows results for all companies. Conditional formatting is used for better orientation. Green colour means accept, orange is under consideration and red is reject.

Table 19: MS Excel result – chart (source: own work)



5.2 MATLAB results

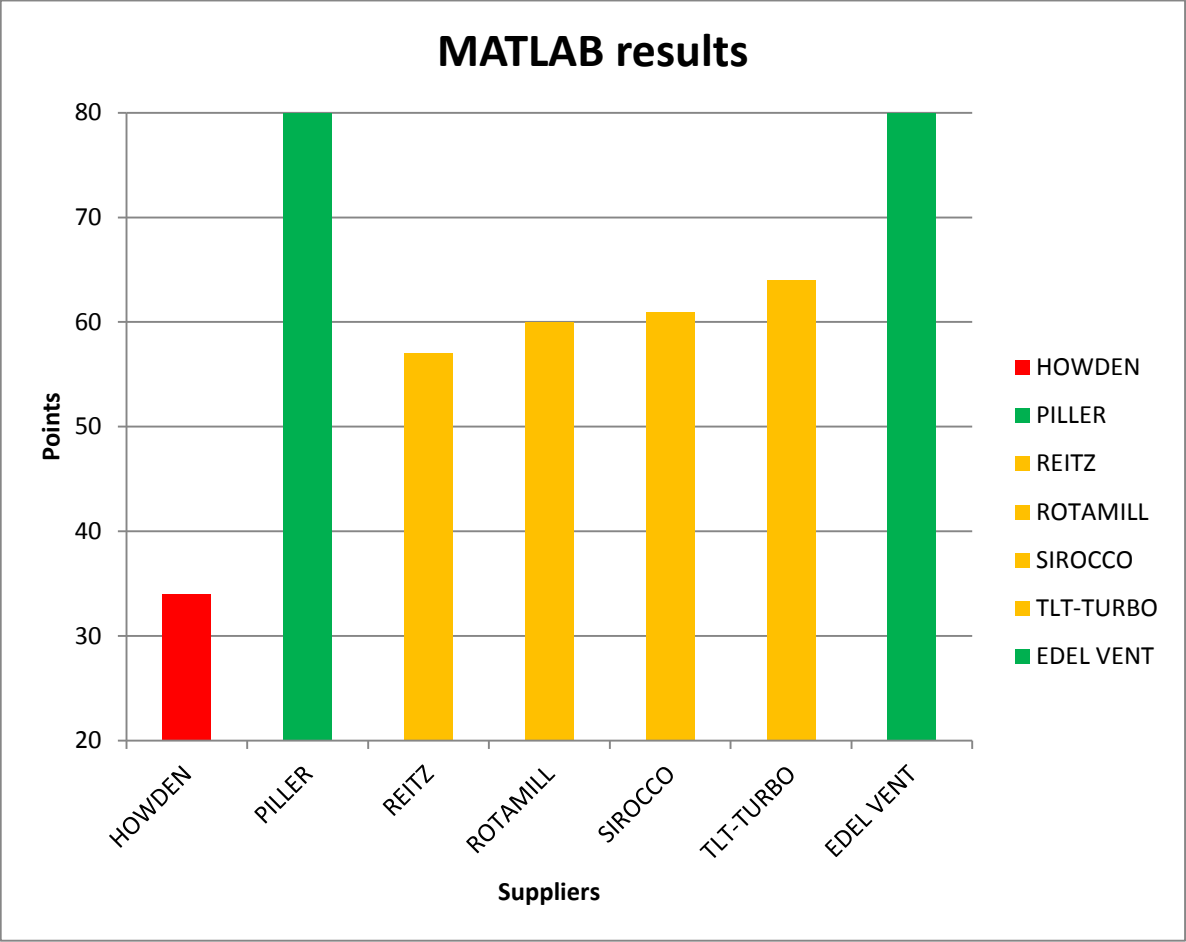
Table 19 displays results from the MATLAB. Piller and Edel Vent scored both 80 points resulting with recommendation “Accept”. Howden scored 41 points with recommendation “Reject”. Rest of the companies scored 60 points in average with recommendation “Under consideration”.

Table 20: MATLAB result (source: own work)

Supplier	Results	Recommendation
HOWDEN	34	REJECT
PILLER	80	ACCEPT
REITZ	57	UNDER CONSIDERATION
ROTAMILL	60	UNDER CONSIDERATION
SIROCCO	61	UNDER CONSIDERATION
TLT-TURBO	64	UNDER CONSIDERATION
EDEL VENT	80	ACCEPT

Maximum that could be achieved in the MATLAB results is 80 points. Also minimum is 20.

Table 21: MATLAB result - chart (source: own work)



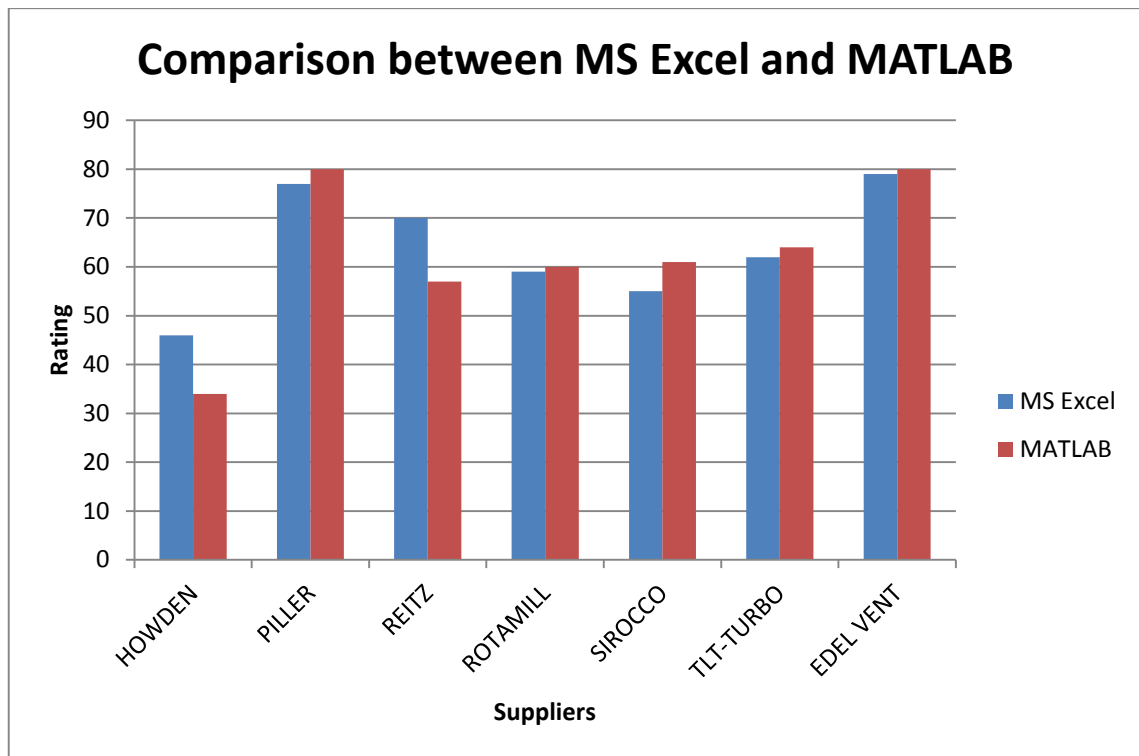
5.3 Comparison between MS Excel and MATLAB

In the last part of the results we can see the comparison of the results obtained from MS Excel and MATLAB. As can be seen in the picture table below recommendations for each company remains the same.

Table 22: Comparison between MS Excel and MATLAB (source: own work)

Supplier	MS Excel	MATLAB
HOWDEN	46	34
PILLER	77	80
REITZ	70	57
ROTAMILL	59	60
SIROCCO	55	61
TLT-TURBO	62	64
EDEL VENT	79	80

As mentioned before range for MS Excel is from 0 to 100 and for MATLAB it is 20 to 80. However results still pretty much the same. Biggest difference in the results we can observe for the HOWDEN and REITZ companies. First named company in the both fuzzy models scored closely to reach “Under Consideration” recommendation. On the other hand REITZ scored 70 points in the MS Excel and only 57 in MATLAB.



Picture 44: Comparison between MS Excel and MATLAB (source: own work)

6 DISCUSSION

In this master thesis were created two decision-making systems based on fuzzy logic. Both models are designed to ease supplier evaluation process for the staff in the company. MS Excel and MATLAB were used for creating these models.

MS Excel model offers simple design and easy for understand usage. Since everything is thoroughly described it is possible to edit parameters of the model. Possible amendments are possible through transformation matrix and state matrix for each supplier. In case that company will stick to MS Excel decision-making system it is possible to design extension through Virtual Basic language.

MATLAB model created in the fuzzy logic toolbox serves as control mechanism which either confirms or denies results from MS Excel. In the author's opinion MATLAB as program is less user-friendly and harder to orientate for less experienced user. MATLAB license is quite expensive as well while MS Excel is installed by default in the MS Office package.

By testing both models they provided almost the same evaluation. Therefore it is confirmed that they are working correctly. Both fuzzy models are using same inputs with negligible difference in the outputs.

Main purpose of the models is to save time during evaluation process. Secondary aim is to clearly arrange all the suppliers so it is easier for the staff to decide which supplier to choose. Later it is possible to create extension for supplier rating printed form so it can be sent to the suppliers with some proposals for better cooperation.

Both fuzzy models can be used for evaluation of other suppliers. In the case of MS Excel there is need to add another transformation matrix and evaluation line. On the other hand MATLAB in the current state is just evaluation process so there is no need for the edition. MS Excel is more approachable since every computer in the company

is installed with MS Office package. Nevertheless it is possible to transfer evaluation proces from the MATLAB to the .exe file so there will be no need of the Mathworks MATLAB software.

Both models presented same recommendations – reject, under consideration or accept. Likewise same linguistic variables are being evaluated (Product price, Payment terms, Price negotiation, Delivery time, Delivery costs, Delivery reliability, Product quality, Supplier Willingness and Technological capabilities).

7 CONCLUSION

Nowadays it is important for the companies to have competitive advantage on the market. One way to achieve it is optimize costs on the supplies. Not necessary to lower the costs and reduce the quality but to choose the most adequate suppliers. Then companies are able to achieve stable performance and efficiency. This goal can be achieved by implementing supplier evaluation model to ease the decision-making process. Thanks to these models staff can evaluate supplier much faster and with less effort.

This diploma thesis deals with creation of such fuzzy models using MS Excel and MATLAB. This models serves for evaluation of suppliers for the První brněnská strojírna a.s.

Diploma thesis started with theoretical basics of supplier evaluation process. Followed by basics of fuzzy logic and modelling of fuzzy systems. Terms such as fuzzy logic, fuzzy sets and membership functions were explained. To the end of the theoretical part basic work in the MS Excel were explained and MATLAB so even less experienced were able to understand principles of both fuzzy models.

Followed by analytical part where the basic information about company is stated with brief description of the target purchase product. In the second part seven possible suppliers are briefly presented. Last part is evaluation criteria are interpreted with succinct explanation why were such criteria selected.

Own proposals deals with creation of fuzzy models first at the MS Excel and afterwards in the MATLAB. In the MS Excel description and transformation matrixes were created. For each supplier state matrix was created. It is possible later to amend this matrix to enter possible changes related to the supplier e. g. change in price or delivery term etc. Scalar count was used to evaluate suppliers and table with rating were created. Using conditional formatting table is sorted by the colours for easier orientation. System were designed in the way that user cannot enter values wrongly otherwise error

evaluation is achieved. Evaluation table reflects if supplier received recommendation accept, under consideration or reject.

Next was fuzzy model created at the MATLAB for that Fuzzy Logic Toolbox was used. For simplification and reduction number of the rules criteria were divided in the three groups which serves as inputs for evaluation process. Afterwards evaluation file were created which defines result interpretation. Lastly M. file was created where all inputs are entered after launch. In the end when all inputs are entered result is expressed both numerically and linguistically. Same as for MS Excel recommendation which can be achieved is accept, under consideration or reject.

In the last part of this diploma thesis achieved results from both fuzzy models are presented and compared between each other. Results were negligibly close so it is confirmed that both systems are working correctly. In the both models company Howden achieved the lowest result finishing with recommendation “Reject”. Also in the both systems companies Piller and Edel Vent achieved great results allows them to achieve “Accept” recommendation.

Both models should be able to serve the company during supplier evaluation process. Also both models can be later expanded with various tools for advanced usage. For purpose of the diploma thesis and initial usage at the company such state of fuzzy models is sufficient.

In the authors opinion aim of this diploma thesis was fulfilled. Results achieved through fuzzy models reflects reality. Both models should be able to help company to optimize supplier evaluation process.

REFERENCES

ALAVALA, C.R., 2008. *Fuzzy Logic and Neural Networks : Basic Concepts and Application*. Daryaganj, Delhi, IND: New Age International.

DOSTÁL, P., 2015. *Soft computing v podnikatelství a veřejné správě*. 1. edn. Brno: Akademické nakladatelství CERM.

DOSTÁL, P., 2012. *Pokročilí metody rozhodování v podnikatelství a veřejné správě*. 1. edn. Brno: Akademické nakladatelství CERM.

DOSTÁL, P., 2008. *Pokročilé metody analýz a modelování v podnikatelství a veřejné správě*. Brno: Akademické nakladatelství CERM.

EDEL VENT, 2016-last update, Edel Vent. Available: <http://www.edelvent.sk/en/> [07/01, 2016].

GLOBALMARKET GROUP, 2016-last update, Y5-12, China Y5-48 Single Inlet Industrial Boiler Fan. Available: <http://www.globalmarket.com/product-info/y5-48-single-inlet-industrial-boiler-centrifugal-exhaust-fan-2222861.html> [07/01, 2016].

GOODROW, C., 2016-last update, What it takes to sell. Available: <https://chrisgoodrow.wordpress.com/tag/buying-cycle/> [06/25, 2016].

HOWDEN GROUP, 2016-last update, Howden Axial Fans - Overview. Available: <http://www.howden.com/AboutUs/bu/HAXS/pages/overview.aspx> [07/01, 2016].

JURA, P., 2003. *Základy fuzzy logiky pro řízení a modelování*. Brno: Vysoké učení technické: VUTIAM.

LUKOSZOVÁ, X., 2004. *Nákup a jeho řízení*. 1 edn. Brno: Computer Press.

MATHWORKS, 2016-last update, MATLAB Fuzzy Logic Toolbox - User's guide. [Homepage of The MathWorks], [Online]. Available: http://cn.mathworks.com/help/pdf_doc/fuzzy/fuzzy.pdf [06/29, 2016].

NEELY, A.D., RICHARDS, H., MILLS, J., PLATTS, K. AND BOURNE, M., 1997. Designing performance measures: a structured approach. *International Journal of Operations & Production Management*, **17**(11), pp. 1131-52.

OSIRO, L., LIMA-JUNIOR, F.R. and CARPINETTI, L.C.R., 2014. A fuzzy logic approach to supplier evaluation for development. *International Journal of Production Economics*, **153**, pp. 95-112.

PBS BRNO, 2015-last update, PBS Brno. Available: <http://www.pbs.cz/en-gb/home> [04/01, 2016].

PILLER, 2016-last update, Piller profile. Available: <http://www.piller.de/> [07/01, 2016].

PRAJOGO, D., CHOWDHURY, M., YEUNG, A.C.L. and CHENG, T.C.E., 2012. The relationship between supplier management and firm's operational performance: A multi-dimensional perspective. *International Journal of Production Economics*, **136**(1), pp. 123-130.

REITZ GROUP, 2016-last update, Reitz Ventilatoren. Available: <http://www.reitz-ventilatoren.de/en/reitz/> [07/01, 2016].

ROTAMILL ANLAGEN-, APPARATE-, VENTILATORENBAU GMBH, 2016-last update, Company: ROTAMILL. Available: <http://www.rotamill.de/en/company/> [07/01, 2016].

SCHOENHERR, T., MODI, S.B., BENTON, W.C., CARTER, C.R., CHOI, T.Y., LARSON, P.D., LEENDERS, M.R., MABERT, V.A., NARASIMHAN, R. and WAGNER, S.M., 2012. Research opportunities in purchasing and supply management. *International Journal of Production Research*, **50**(16), pp. 4556-4579.

SIROCCO LUFT- UND UMWELTTECHNIK GMBH, 2016-last update, Sirocco - About Us. Available: http://www.sirocco.at/sir/content.php?Page_ID=43 [07/01, 2016].

TALLURI, S. and SARKIS, J., 2002. A model for performance monitoring of suppliers. *International Journal of Production Research*, **40**(16), pp. 4257-4269.

TLT-TURBO GMBH, 2016-last update, TLT-Turbo GmbH. Available: <http://www.tlt-turbo.com/EN/startseite.html> [07/01, 2016].

TOMEK, J., 1999. *Moderní řízení nákupu podniku*. 1 edn. Praha: Management Press.

LIST OF ABBREVIATIONS

PP	Product Price
PT	Payment terms
PN	Price negotiation
DT	Delivery time
DC	Delivery costs
DR	Delivery reliability
PQ	Product quality
TC	Technological capabilities
SW	Supplier willingness

LIST OF TABLES

Table 1: Transformation matrix – description	20
Table 2: Transformation matrix – criterias with weights.....	21
Table 3: State matrix	22
Table 4: State matrix – changed	22
Table 5: Retransformation matrix	23
Table 6: Explanations of abbreviations used in MS Excel.....	40
Table 7: Description matrix	40
Table 8: Transformation matrix	40
Table 9: Scalar products	41
Table 10: Howden supplier evaluation	42
Table 11: Error in supplier rating.....	43
Table 12 - Error in the supplier ratings.....	43
Table 13: Supplier rating	44
Table 14: Output 1 for Price+Finance	47
Table 15: Output range for Delivery terms.....	49
Table 16: Output 3 for Quality + Innovation.....	51
Table 17: Range for supplier evaluation.....	55
Table 18: MS Excel result	58
Table 19: MS Excel result – chart	59
Table 20: MATLAB result	60
Table 21: MATLAB result - chart.....	61
Table 22: Comparison between MS Excel and MATLAB	62

LIST OF PICTURES

Picture 1: Fuzzy logic approach to supplier evaluation	13
Picture 2: Purchase process	15
Picture 3: Clearly visible and fuzzy boundary	17
Picture 4: Progress and definition of Γ function	17
Picture 5: Progress and definition of L function.....	17
Picture 6: Progress and definition of \wedge function	18
Picture 7: Progress and definition of Π function.....	18
Picture 8: Intersection of two triangular numbers	18
Picture 9: Union of two triangular fuzzy numbers	19
Picture 10: Complement of fuzzy sets	19
Picture 11: Fuzzy process.....	19
Picture 12: Entry table for tablet parameters.....	21
Picture 13: Entry table for tablet parameters - changed	22
Picture 14: Main tools of fuzzy inference system.....	24
Picture 15: FIS Editor	25
Picture 16: MF Editor	26
Picture 17: Rule Editor.....	27
Picture 18: Rule Viewer	28
Picture 19: Surface Viewer	29
Picture 20: PBS Brno.....	30
Picture 21: Industrial boiler fan - example	31
Picture 22: Howden company logo.....	32
Picture 23: Piller company logo.....	33
Picture 24: Reitz Ventilatoren company logo.....	33
Picture 25: Rotamill company logo	34
Picture 26: Sirocco company logo	34
Picture 27: TLT-Turbo GmbH company logo	35
Picture 28: Edel Vent company logo	35
Picture 29: Diagram for MATLAB procedure	45
Picture 30: MF Editor for Price + Finance.....	46

Picture 31: Membership functions for Price+Finance	47
Picture 32: MF Editor for Delivery Terms.....	48
Picture 33: Membership functions for Delivery terms.....	49
Picture 34: MF Editor for Quality + Innovation	50
Picture 35: Membership functions for Quality + Innovation	51
Picture 36: Rule Editor for Product + Price.....	52
Picture 37: Rules construction in the FIS file.....	53
Picture 38: Rule Viewer for Final	53
Picture 39: M-file	54
Picture 40: Start of M-file	55
Picture 41: Command Window - start of the M-fil.....	55
Picture 42: MF Editor Final	56
Picture 43: Surface viewer Final	57
Picture 44: Comparison between MS Excel and MATLAB	63

LIST OF APPENDICES

APPENDIX 1: LIST OF REFERENCES	I-II
APPENDIX 2: LIST OF SUPPLIERS.....	III
APPENDIX 3: SUPPLIER EVALUATIONS	IV-V
APPENDIX 4: NUMBERS ENTERED IN MATLAB FOR EACH SUPPLIER ...	VI

Project	Country	Year	Boiler load (t/h)	Steam Pressure (Mpa)	Steam temperature (°C)	Fuel / Description
Píseňská Energetika	Czech Republic	2015	25	1,4	300	Natural gas, packed boiler
Třebovice DeNOx	Czech Republic	2015	80	12,75	500	Primary and SNCR based secondary measurements
Mariánské lázně, heating plant	Czech Republic	2014	12	3,4	397	Membrane wall, biomass boiler
MONDI Štětí	Czech Republic	2013	130	9,3	535	Pressure part reconstruction
Žarnovica	Slovak Republic	2013	35	3,78	475	Membrane wall, biomass boiler
Domoradice, steam boiler	Czech Republic	2012	35	6,9	470	Complete supply of biomass boiler house
Kutná Hora, steam boiler	Czech Republic	2011	30	4	400	Membrane wall, biomass boiler
Krnov, heating plant - steam boiler	Czech Republic	2009	35	3,75	475	Membrane wall, biomass boiler
Power plant Opatovice - Chrudim hot water boiler	Czech Republic	2005	35 MW	hot water	/	Natural gas hot water boiler
Pforzheim, heating plant	Germany	2005	52,5	6,2	450	Contaminated biomass boiler
BMKW Wicker	Germany	2005	55	6,7	450	Contaminated biomass boiler
VIPAP VIDEM Krško	Slovenia	2002	60	4,5	450	Natural gas + waste heat boiler
ZSNP Žiar nad Hronom	Slovak Republic	2002	30	1,3	350	Natural gas + waste heat boiler
PRECHEZA Přerov	Czech Republic	2001	15	2,95 2,95	270 370	Boiler for flue gases from H2SO4 production
Heating plant RADVAŇ	Slovak Republic	1999	8,8MW	/	/	HRSG boiler
Heating plant KYJOV	Czech Republic	1999	13,8	4,4	475	HRSG boiler
Windel	Germany	1997	35	4,8	450	HRSG boiler
Z88	Netherlands	1997	35	4	450	HRSG boiler
KDZ	Czech Republic	1997	25	3,8	445	HRSG boiler
Cebeson	Netherlands	1995	24	1,6	204	HRSG boiler
VŠZ Košice	Slovak Republic	1993	215	9,81	540	Low LHV coal, gas
Mohndruck	Germany	1993	15	4,5	540	HRSG boiler
BZ Ružomberok	Slovak Republic	1991	75	3,9	440	Natural gas
Power plant Iranshahr	Iran	1991	300	13,5	540	HHO
Slovnaft Bratislava	Slovak Republic	1991	140	9,41	535	HHO + Natural gas
Power plant Píseň ELU III - retrofit	Czech Republic	1991	150	9,41	540	Lignite
ZT Zlín	Czech Republic	1991	80	1,32	250	Natural gas
Power plant Vojany I - retrofit	Czech Republic	1991	350	13,63	540	Low LHV coal
Heating plant Hudiksvall - retrofit	Sweden	1991	65,5	6,7	475	Peat, waste wood
VŠZ Košice	Slovak Republic	1991	32	4	445	HRSG boiler
Power plant Ružomberok	Slovak Republic	1990	75	3,9	440	Natural gas
Power plant Zlín	Czech Republic	1990	80	1,32	250	Natural gas
Slovnaft Bratislava	Slovak Republic	1990	140	9,41	535	HO + Natural gas
Duslo Šála	Slovak Republic	1990	125	9,41	540	Lignite
NH Kunčice - reconstruction	Czech Republic	1990	220	9,5	480	Coal
NH Kunčice - reconstruction	Slovak Republic	1990	220	9,5	480	Coal
Heating plant Povážská Bystrica	Slovak Republic	1990	125	9,41	540	Lignite
Heating plant Přerov	Czech Republic	1990	110	1,32	235	Coal
VŠZ Košice	Slovak Republic	1990	32	4	445	HRSG boiler
Heating plant Přerov	Czech Republic	1989	110	1,32	235	Coal
UFA	Russia	1989	23,8	/	/	Natural gas + refinery gas
Heating plant Olomouc	Czech Republic	1988	75	1,32	220	HO + Natural gas
Slovnaft Bratislava	Slovak Republic	1988	140	9,41	535	HO + Natural gas
Power plant Talkha	Egypt	1988	150	9,41	540	HO
Power plant Povážská Bystrica	Slovak Republic	1988	125	9,41	540	Lignite
Power plant Vojany	Czech Republic	1988	350	13,63	540/535	Low LHV Coal
Slovnaft Bratislava	Slovak Republic	1988	37,1	/	/	Natural gas + refinery gas
Púchov	Slovak Republic	1987	70	2,16	315	HO + Natural gas
MEZ Mohelnice	Czech Republic	1987	25	3,73	445	Natural gas
Nuclear power plant Temelin	Czech Republic	1987	25	1,32	220	Natural gas
Power plant Siouf Alexandria	Egypt	1987	140	7,36	525	HO
Heating plant Liberec	Czech Republic	1987	115	1,32	280	Natural gas
Heating plant Košice III	Slovak Republic	1987	140MW	hot water	/	Coal
Omsk	Russia	1987	23,8	/	/	Natural gas + refinery gas
MEZ Mohelnice	Czech Republic	1986	50	3,73	445	Natural gas
SEPAP Štětí	Czech Republic	1986	220	9,41	540	Lignite + waste wood
Metallurgy Třinec	Czech Republic	1986	5,54MW	hot water	/	HRSG boiler
SEPAP Štětí II	Czech Republic	1986	220	9,41	540	Lignite + waste wood
Lisiansk	Ukraine	1986	23,8	/	/	Natural gas + refinery gas
Zetor Brno	Czech Republic	1985	75	6,4	485	HO + Natural gas
TEC Republika II	Bulgaria	1985	220	9,41	540	Lignite
Power Trmice IV	Czech Republic	1985	115	1,8	235	Lignite
Heating plant Oradea II	Romania	1985	420	13,63	540	Lignite
Groznyj	Chechen Republic	1985	23,8	/	/	Natural gas + refinery gas
Mazejkaj	Lithuania	1985	23,8	/	/	Natural gas + refinery gas
Las Camariocas	Cuba	1984	75	3,73	450	HO
BAZ Bratislava	Slovak Republic	1984	75	1,32	210	HO
Thaton	Burma	1984	40	3,73	445	HO
Refinery Homs VI	Syria	1984	190	9,41	540	HO + Gas
Abu Dhabi Umm al Nar	Arabské emiráty	1984	40	2,3	280	NG + diesel
Metallurgical plant Bohumín	Czech Republic	1984	80	3,9	450	HO

Project	Country	Year	Boiler load (t/h)	Steam Pressure (Mpa)	Steam temperature (°C)	Fuel / Description
FN Bohunice Brno	Czech Republic	1984	11,63MW	hot water	/	HO + Natural gas
VS2 Košice III	Slovak Republic	1984	215	13,63	540	Low LHV coal + Natural gas
VS2 Košice III	Slovak Republic	1984	215	13,63	540	Low LHV coal + Natural gas
VS2 Košice	Slovak Republic	1984	225	13,63	540	Coal
Power plant Bratislava	Slovak Republic	1983	75	1,32	250	HO
Refinery Salahuddin	Iraq	1983	100/120	3,24	410	HO + Natural gas + Refinery gas
Škoda Pízeň - ELU III	Czech Republic	1983	160	13,63	540	Lignite
TOFA Albrechtice	Czech Republic	1982	12	1,47	360	HO + Waste wood
Škoda Pízeň - ELU III	Czech Republic	1982	160	9,41	540	Lignite
TOFA Albrechtice	Czech Republic	1982	12	1,37	360	HO + Waste wood
Heating plant Košice II	Slovak Republic	1980	230	13,63	540	Low LHV coal + Natural gas
Heating plant Brno - sever II	Czech Republic	1980	115	1,32	240	HO
TEC Plovdiv II	Bulgaria	1980	220	9,41	540	HO + Natural gas
Refinery Salahuddin	Iraq	1980	100/120	3,24	410	HO + Natural gas + Refinery gas
TEC Plovdiv II	Bulgaria	1980	50	1,57	250	HO + Natural gas
Heating plant Holešovice	Czech Republic	1980	115	1,57	260	HO + Natural gas
Power plant Trajčo Kostov II	Bulgaria	1979	220	13,63	535	HO + Natural gas
Heating plant Košice II	Slovak Republic	1979	230	13,63	540	Low LHV coal + Natural gas
Sugar refinery Sládkovičovo	Slovak Republic	1978	10	0,78	190	HO
SCP Ružomberok	Slovak Republic	1978	75	6,37	465	HO
CCH Zarnesti	Romania	1978	75	3,92	450	HO + Waste gas
Martin III	Slovak Republic	1978	58,15MW	hot water	/	HO
Sofia - sever	Bulgaria	1978	220	9,81	540	HO + Natural gas
Power plant Homs IV	Syria	1978	265	9,41	540	HO
FN Bohunice Brno	Czech Republic	1978	16	1,32	220	HO + NG + Medical waste
Heating plant Košice II	Slovak Republic	1978	116,3MW	hot water	/	Low LHV Coal
CCH Zarnesti	Romania	1978	75	3,92	450	HO
Heating plant Košice II	Slovak Republic	1978	116,3MW	hot water	/	Low LHV Coal
FN Bohunice Brno	Czech Republic	1978	16	1,32	220	HO + NG + Medical waste
Misir Rayon Kafr el Dawar	Egypt	1977	50	4,71	460	HO
Beida Dyers III	Egypt	1977	50	4,51	470	HO
TEC Pleven II	Bulgaria	1977	120	4,12	450	HO
Sugar refinery Šurany	Slovak Republic	1977	8	1,32	220	HO
Incinerator Jablonec n. N.	Czech Republic	1977	25	1,32	220	HO
Škoda Pízeň - ELU III	Czech Republic	1977	75	1,67	350	HO
Incinerator Minsk	Belarus	1977	/	/	/	Communal waste burning
Power plant Iquitos	Peru	1976	55	3,04	410	HO
Fruta Modřice	Czech Republic	1976	12	1,67	250	HO + Natural gas
Vertex Hodonice	Czech Republic	1976	8	0,98	190	Natural gas
Dolné Vestenice	Slovak Republic	1976	25	1,76	305	Natural gas
Merina Trenčín	Slovak Republic	1976	35	3,12	445	HO
Sugar refinery Šurany	Slovak Republic	1976	50	3,73	445	HO
ZA Pulawy III	Poland	1976	215	9,41	540	Coal
Heating plant Přerov	Czech Republic	1976	100	1,32	235	Coal
Incinerator Taškent	Uzbekistan	1976	/	/	/	Communal waste burning
Incinerator Vladivostok	Russia	1976	11	250	/	Communal waste + HRSG
Heating plant Liberec	Czech Republic	1975	75	1,32	250	HO
Heating plant Liberec	Czech Republic	1975	115	9,41	540	HO
PLEAS Havlíčkův Brod	Czech Republic	1975	12	1,32	210	HO
Sugar refinery Šurany	Slovak Republic	1975	50	3,82	445	HO
Heating plant Trnava II	Slovak Republic	1975	50	1,47	240	HO + HRSG
JMP Mikulov	Czech Republic	1975	8,72MW	hot water	/	HO + Natural gas
Rafinerie Homs III	Syria	1975	25	3,82	450	HO + Benzin + Refinery gas
Beida Dyers II	Egypt	1975	50	4,61	470	HO
Power plant Pucallpa	Peru	1975	55	3,04	410	HO
Heating plant Otrokovice	Czech Republic	1975	125	6,41	540	Lignite
TOFA Albrechtice	Czech Republic	1975	12	1,37	360	HO + Waste wood
Heating plant Trnava II	Slovak Republic	1975	50	1,47	240	HO + HRSG
Metallurgical plant Zenica	Bosna and Herzegovina	1974	220	9,41	540	Lignite + waste gas
Rubber factory 1.mája Púchov II	Slovak Republic	1974	50	2,16	315	HO + HRSG
ZA Pulawy III	Poland	1974	215	9,41	540	Coal
Rubber factory 1. mája Púchov I	Slovak Republic	1974	50	2,16	315	HO + HRSG
Incinerator Tbilisi	Georgia (country)	1974	/	/	/	Communal waste burning
Škoda Pízeň - ELU III	Czech Republic	1973	75	1,67	350	HO
Elektrosvit Nové Zámky	Slovak Republic	1973	25	1,32	220	HO
Železnorudné baně Nižná Slaná	Slovak Republic	1973	10	1,32	220	Natural gas
Metallurgical plant Bohumin	Czech Republic	1973	80	3,73	450	HO
Heating plant Olomouc	Czech Republic	1973	75	1,32	220	HO
TEC Plovdiv I	Bulgaria	1973	220	9,41	540	HO
PLEAS Havlíčkův Brod	Czech Republic	1973	12	1,32	210	HO
Heating plant Växjö	Sweden	1973	140	10,3	535	HO
Technoplast Chropyně II	Czech Republic	1973	50	3,73	450	HO
Power plant Vojany II	Czech Republic	1973	355	13,63	535	HO
Metallurgical plant Zenica	Jugoslavia	1973	220	9,41	540	Lignite + waste gas
Heating plant Banská Bystrica - Radvaň	Slovak Republic	1972	4	1,32	220	Natural gas
Heating plant Banská Bystrica	Slovak Republic	1972	29MW	hot water	/	HO
Beida Dyers	Egypt	1972	50	4,61	470	HO

Name of equipment	Manufacturer	Country of Origin
Boiler	První brněnská strojírna, a.s. (PBS Brno)	CZ
Grate	Intek	DE
	Detroit Stoker	US
ESP	ZVVZ	CZ
	ELWO	PL
	AE&E LENTJES	DE/CZ
	FISIA	DE
	HAMON	DE
Fans	HOWDEN	FR/DE/UK
	PILLER INDUSTRIE VENT.	DE
	REITZ	DE
	ROTAMILL	DE
	SIROCCO	AT
	TLT	DE/AT
Blowers	AERZEN	DE
	ATLAS COPCO	DE
	COMPAIR	DE
	KAESER	DE
Soot blowers	Clyde Bergemann	DE
	Diamond Power	UK
	EKSTROM	SE
	MEHLDAU&STEINFATH	DE
	ROSINK	DE
HP & IP By-Pass	SEMPPELL	DE
	TYCO	DE
	BOPP&REUTHER	DE
	CCI	US
	COPEL VULCAN	UK
	G - TEAM	CZ
	LDM	CZ
Silencers	Aarding Thermal Acoustics BV	NL
	Baucomex CZ	CZ
	Glaunach	AT
	Gradior Power	CZ
	Greif-Akustika	CZ
Start-up Burners & Bed Lances	Saake	DE
	JOHN ZINK TODD	LU/UK
	Mehldau & Steinfath	DE
	DUMAG	AUT
Steam Turbine	SIEMENS	DE/CZ
	ŠKODA POWER	CZ
	POWER MACHINES	RU
	PBS ENERGO	CZ

HOWDEN

S1	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	0	1	0	1	1
2	0	0	0	0	0	0	1	0	0
3	0	0	0	1	1	0	0	0	0
4	1	0	0	0	0	0	0	0	0
5		1	1						0
1	1	1	1	1	1	1	1	1	1

□

PILLER

S2	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	0	1	1	0	0
2	0	1	0	1	1	0	0	1	1
3	1	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5		0	0						0
1	1	1	1	1	1	1	1	1	1

REITZ

S3	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	1	1	1	1	0
2	0	0	0	1	0	0	0	0	1
3	1	0	0	0	0	0	0	0	0
4	0	1	1	0	0	0	0	0	0
5		0	0						0
1	1	1	1	1	1	1	1	1	1

ROTAMILL

S4	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	1	1	1	0
3	1	1	1	1	0	0	0	0	1
4	0	0	0	0	0	0	0	0	0
5		0	0						0
1	1	1	1	1	1	1	1	1	1

SIROCCO

S5	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	1	1	0	1
3	1	0	0	0	1	0	0	1	0
4	0	1	1	0	0	0	0	0	0
5		0	0						0
1	1	1	1	1	1	1	1	1	1

TLT-TURBO

S6	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	0	0	1	0	0
2	0	1	1	0	1	1	0	1	1
3	0	0	0	1	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0
5		0	0						0
1	1	1	1	1	1	1	1	1	1

EDEL VENT

S7	PP	PT	PN	DT	DC	DR	PQ	TC	SW
1	0	0	0	0	1	0	0	0	1
2	1	1	1	1	0	0	1	1	0
3	0	0	0	0	0	1	0	0	0
4	0	0	0	0	0	0	0	0	0
5		0	0						0
1	1	1	1	1	1	1	1	1	1

Numbers inserted into Matlab:

HOWDEN	40	40	40
	75	100	100
	75	100	100
PILLER	90	90	70
	80	80	90
	100	90	90
REITZ	90	50	90
	80	90	90
	100	95	90
ROTAMILL	90	45	45
	80	70	70
	60	60	40
SIROCCO	90	60	40
	85	60	70
	60	55	65
TLT-TURBO	50	60	70
	75	80	75
	70	65	60
EDEL VENT	85	95	90
	90	90	90
	80	85	95