THE PROPOSAL OF USING FUZZY MODEL FOR THE WAREHOUSE MANAGEMENT

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Abstract

The aim of the paper is to present the possibility of application the fuzzy sets theory to support warehouse management. In the second chapter the basic issues relating to fuzzy sets and fuzzy logic are presented. The third chapter shortly characterizes the company and shows results of classical ABC / XYZ analysis. The conception of a fuzzy model used to plan the deployment of the goods in the warehouse of electric parts is presented in the fourth chapter. The created fuzzy model allowed the reorganization of the placement of products to improve the process of orders picking. It can be used even in cases when data of sales volume, sales dynamics and weight of the product are not exact or when the classical allocation to group in ABC / XYZ method is not possible.

Keywords: Warehouse management, logistics, fuzzy sets, ABC / XYZ method

1. INTRODUCTION

The fuzzy set theory is successfully used in many fields of science and engineering for many years. Its main advantage is the ability to operate on uncertain and incomplete data that are often determinated by subjective assessments of expert. Fuzzy sets are applied for example in the theory and practice of control systems [1], [2], [3], in the area of systems reliability [4], [5], [6], in the estimation of the various types of risk [7], [8], [9], as well as in logistics [10], [11], [12].

Essential meaning for the efficient organization of the warehouse management has the choice of the method of the goods storage in the warehouse area The good arrangament of products allows you to minimize the work of means of transport, as well as allows to reduce the time of the warehouse operations related to orders picking. After the delivery the goods are divided into relevant loading units and are placed by the workers in the location that was previously established by specified method. The deployment methods are implemented differently depending on the preset level of the indicators and factors such as: the technical conditions, the type of warehouse, the flexibility requirements, the safety requirements and established strategies. Most importantly, these methods are often modified if the implemented solution does not meet expectations of the organization.

There are two main methodologies of goods deployment in storage space that are used for many years [13] - the storage method of permanent allocation and the storage method of free allocation. In addition to the storage method of products an important role plays the way of the management of the warehouse space. One of the most popular ways of the deployment is the arrangement of the products based on the ABC analysis, XYZ analysis or their synthesis. If you are using ABC / XYZ analysis the storage system is planned in such a way that the goods of AX group (i.e. with a high sales volume and low sales dynamics) should be located close to the shipping area, while from the YZ group (i.e. low sales volume and high sales dynamics) are placed far away from this zone. More advanced methods are created based on, among others, artificial neural networks, genetic algorithms, fuzzy logic, etc.

In this paper the proposal of the use of fuzzy logic to goods allocation in the warehouse space in order to improve orders picking process is presented. The aim is to reduce the picking time and to reduce the use of means of transport.

In the second chapter the fuzzy set theory is shortly described while in the third chapter the researched company is characterised as well as the results of classical ABC / XYZ analysis are discussed. The fourth section is about fuzzy model that was created to support the warehouse management of distribution company. In proposed model to sales volume and sales dynamics criteria the additional criterion is taking into account - the weight of the product that is stored in the warehouse.

2. FUZZY SET THEORY

The concept of Fuzzy Sets was introduced by Lotfi Zadeh in 1965 [14] as a generalization of Classical Sets Theory. According to fuzzy sets theory the certain element of a space X may belongs partially to set A and partially to its complement. Fuzzy sets are defined by membership function that is the equivalent of the characteristic function in classical sets theory where certain element if belongs to set A cannot belongs to its complement. In fuzzy set to every element of space X is assigned the value that specifies the level of belonging to given set. Membership of the standard fuzzy set is contained in the interval [0, 1] and if the maximum value of membership function equals 1 we say about normal fuzzy set. Therefore, the membership function of X:

$$\mu_A : X \to [0,1]$$

We can distinguish three cases:

1) $\mu_A(x) = 1$ - that means full membership to fuzzy set A.
2) $\mu_A(x) = 0$ - that means the lack of the membership to fuzzy set A.
3) $0 < \mu_A(x) < 1$ - that means partial membership to fuzzy set A.

Fuzzy set A includes in fuzzy set B if and only if $\mu_A(x) < \mu_B(x)$ for every $x \in X$, while fuzzy set A is equal to fuzzy set B if and only if $\mu_A(x) = \mu_B(x)$.

The membership function may be of different form, such as trapezoid function, triangular function, gauss function, sigmoid function, etc.

Fuzzy sets are subject to the logical operations. Some examples of such operations are given as follows [15]:

1) algebraic product - $C = A \cdot B = \{(x, \mu_A(x) \cdot \mu_B(x)); x \in X\}$
2) algebraic sum - $C = A + B = \{(x, \mu_A(x) + \mu_B(x) - \mu_A(x) \cdot \mu_B(x)); x \in X\}$
3) sum - $\mu_{A \cup B}(x) = \mu(A) \cup \mu(B) = \max\{\mu(A), \mu(B)\}$
4) intersection - $\mu_{A \cup B}(x) = \mu(A) \cap \mu(B) = \min\{\mu(A), \mu(B)\}$
5) negation - $\mu_{\bar{A}}(x) = 1 - \mu_A(x)$.

Decision-making process based on fuzzy logic depends on the fuzzy rules of the form:

IF ..... AND / OR ..... THEN, np.

IF a is A1 AND / OR b is B2 THEN c is C1

IF a is A2 AND / OR b is B1 THEN c is C2,

where a, b, c are the linguistic variables, and A1, A2, B1, B2, C1, C2 are the fuzzy subsets.

Data processing using fuzzy logic is performed in the following steps:

1) Preliminary data processing
2) Fuzzification

3) The interpretation of the IF-THEN rules

4) Defuzzification

5) Final data processing

On the basis on such rules the expert system can be built that will support any decision-making process including operations undertaken in storage process.

3. COMPANY CHARACTERISTICS AND ABC / XYZ ANALYSIS

Analyzed company deals with the distribution of the spare parts dedicated to services of the electrical devices. It was established in 2004 and constantly expanding the range of its products. Currently company includes 86 components in its offer. To ensure the best level of service and rapidly react on demand the company has its own warehouse. In 2015 company sold about 284 thousands of its products. The clients are mostly located in Poland. Data about sales volume for the individual months of 2015 that was used to the assortment analysis were received from the internal transaction system of the company.

ABC analysis allowed to subdivide the offered assortment into three groups. The creation of the three distinct classes of products makes an assessment of the importance of given component and its impact on the total sale of the company easier. The basis of the division was the sales volume in 2015. As a result of the ABC analysis we get the following groups:

- class A - contains of 16 products what makes 18.6% of the overall sale; the lowest sale volume in this group is about 7.5 thousands PCs and with a highest sale volume is about 12 thousands units;
- class B - contains of 30 products what makes 34.9% of the overall sale; the lowest sale volume in this group is less about 2 thousands units;
- class C - contains of 40 products what makes 46.5% of the overall sale; in this group there is one product that was not sale in any single unit.

The next step was the XYZ analysis that allowed to estimate the dynamics of consumption of individual products in 2015. This helps to specify the fluctuations in the demand and create forecast of future sales. As a result, XYZ analysis sets the following groups:

- class X - contains of 32 products what makes 37% of the overall assortment; the limit value of the variance coefficient is 15%;
- class Y - contains of 36 products what makes 42% of the overall assortment; the limit value of the variance coefficient is 40%;
- class Z - contains of 18 products what makes 21% of the overall assortment.

The result of ABC / XYZ analysis is shown in **Table 1**.

Despite the fact that in AX and AY class there are only 16 products their sales volume constitutes more than 50% of the total turnover of the company. The offered portfolio does not include products whose sales volume and sales dynamics would qualify them to AZ class. The largest group in the entire ABC / XYZ matrix is formed by BX class. There are mostly parts for devices in the maturity period of the product life cycle what is the reason of the regularity of their usage. In class BZ there is only one product. The analysis shows also the dead stock in the form of PK-006-000 article. For this position the sales volume in the observed period was 0.

Table 1 Result of ABC / XYZ analysis

		Sales volume		
		A	*B*	*C*
Sales dynamics	***X***	BZ-005-000, PK-007-000, PP-003-002, ZE-003-003, ZL-006-002, ZL-006-007	BZ-001-000, BZ-002-000, BZ-007-000, BZ-010-000, EP-001-001, EP-001-002, EP-001-003, EP-002-002, EP-012-000, EP-013-000, PK-001-000, PK-002-000, PK-003-000, PP-001-001, PP-003-001, PP-013-000, ZD-003-005, ZD-003-007, ZE-003-004, ZE-004-000, ZL-005-000, ZL-006-005	BZ-008-000, PK-002-006, ZD-001-003, ZL-004-000
	Y	EP-002-001, PK-002-007, PK-003-002, PK-009-000, PP-012-000, ZD-001-002, ZE-001-006, ZE-001-009, ZL-002-000, ZL-006-003	BZ-003-000, EP-014-000, PP-002-001, PP-003-003, ZD-001-001, ZD-003-004, ZD-003-006	BZ-006-000, BZ-009-000, EP-001-004, EP-002-005, PK-003-001, PK-004-000, PK-005-000, PK-008-000, PP-001-002, PP-001-003, PP-001-004, PP-001-005, PP-002-002, PP-011-000, ZE-001-004, ZE-001-005, ZE-005-000, ZL-003-000, ZL-006-001
	Z		ZE-001-007	BZ-004-000, EP-002-003, EP-002-004, EP-011-000, PK-006-000, PK-010-000, PP-002-003, ZE-001-008, ZE-002-000, ZE-003-001, ZE-003-002, ZL-001-000, ZL-006-004, ZL-006-006, ZL-007-000, ZL-008-000, ZL-009-000

Source: own elaboration

4. PRODUCTS ALLOCATION WITH THE USE OF FUZZY MODEL

The main purpose of this chapter is to present fuzzy model used for planning the deployment of the goods in the warehouse. The model was created on the basis of previously done ABC / XYZ analysis and other data from the transaction system of the company. As the summary of this chapter the graphical representation of the results of the developed concept is presented.

In the analyzed case the deployment of the products in the warehouse space was done according to three criteria: sales volume, sales dynamics and the weight of the component. One of the assumptions of fuzzy model construction was to place products with highest sales volume and lowest sales dynamics near the shipping area while products with lowest sales volume and highest sales dynamics locate far from the shipping area. As it is known the division for the groups in the classical ABC / XYZ method is sometimes problematic but in presented approach it is not so strict. What is more we do not have to know the exact level of the demand in the past and we may deal better with probable variations of the sale in the future. As it was shown in the previous chapter the sales volume ranges from 0 to about 12 thousand pieces. The variation coefficient ranges from 0 to 0.7. The second assumption was to place the light products far from shipping area while the heavy ones close to this area. The weight of components ranges from 100 g to 14 kg. Above assumptions guarantee the improvement of the completion process by shortening the completion time and reducing the use of transport means.

Table 2 Membership function for fuzzy variables

Variable	In/out	Linguistic term	Type of the membership function	Parameters of the membership function
Sales volume	input	small	Trapezoid	(0;0;1100;2700)
		medium		(1100;2700;6800;8500)
		high		(6800;8500;12250;12250)
Sales dynamics	input	small	Trapezoid	(0.00;0.00;0.12;0.18)
		medium		(0.12;0.18;0.35;0.40)
		high		(0.35;0.40;0.77;0.77)
Weight	input	light	Z-class	(1.7;7.0)
		medium	Gauss	(2.1; 7.0)
		heavy	S-class	(7.0;12.3)
Distance	output	close	Triangular	(0;0;14)
		fairly close		(0;14;24)
		far		(14;24;40)
		very far		(24;40;40)

Source: own elaboration

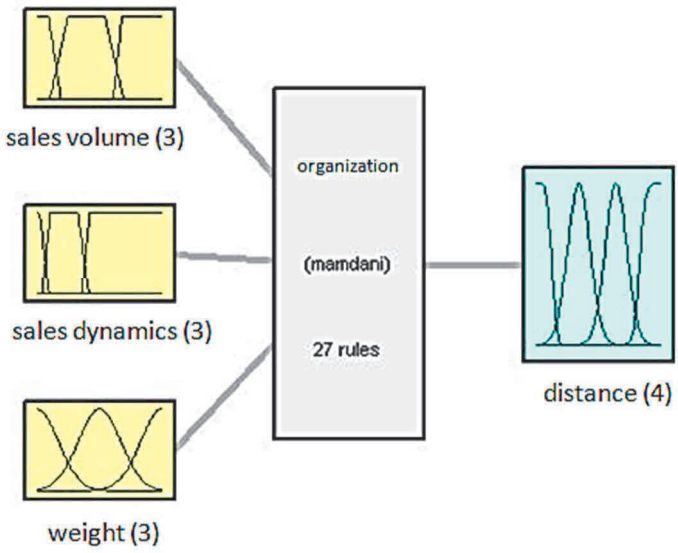

Figure 1 The conceptual scheme of fuzzy model
Source: own elaboration

Due to the relations among inputs the Mamdani model was applied [16]. There are three inputs - sales volume, sales dynamics, product weight and one output - distance. To calculate crisp value of the output the centroid method of the deffuzification was used. In the **Figure 1** the general scheme of the fuzzy model is presented, while in the **Table 2** the linguistic terms of inputs and output with parameters of membership function are included. Graphical representations of the membership functions are show in the **Figure 2**.

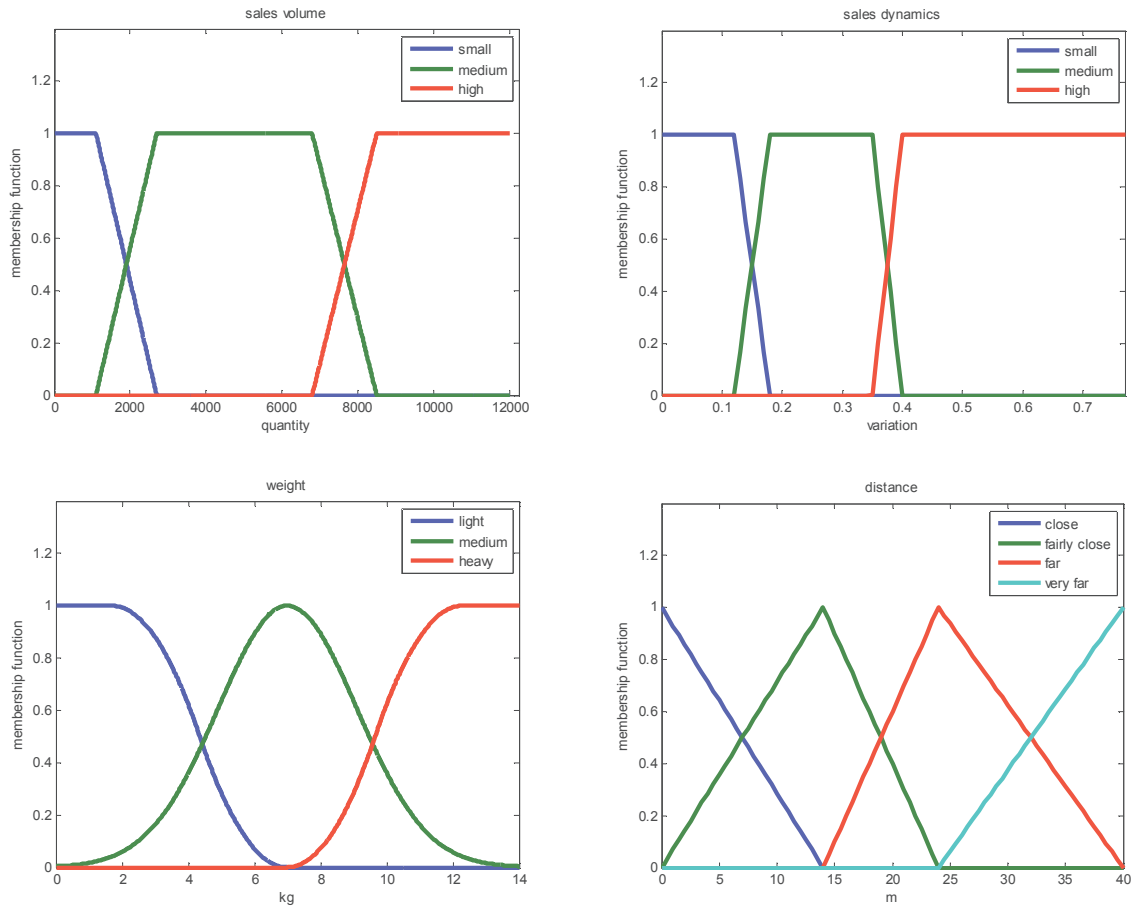

Figure 2 Membership function for a) input variable „sales volume" b) input variable „sales dynamics" c) input variable „weight" d) output variable „distance"
Source: own elaboration

An exemplary rules in the fuzzy logic block ("organization (mamdani) 27 rules) are given beneath:

1) IF "sales volume" is **small** AND "sales dynamics" is **high** AND "weight" is **light** THEN "distance" is **very far**.
2) IF "sales volume" is **small** AND "sales dynamics" is **high** AND "weight" is **medium** THEN "distance" is **very far**.
3) IF "sales volume" is **small** AND "sales dynamics" is **high** AND "weight" is **heavy** THEN "distance" is **far**.
4) IF "sales volume" is **small** AND "sales dynamics" is **medium** AND "weight" is **light** THEN "distance" is **far**.
5) IF "sales volume" is **high** AND "sales dynamics" is **medium** AND "weight" is **light** THEN "distance" is **fairly close**.
6) IF "sales volume" is **high** AND "sales dynamics" is **high** AND "weight" is **light** THEN "distance" is **fairly close**.
7) IF "sales volume" is **high** AND "sales dynamics" is **small** AND "weight" is **medium** THEN "distance" is **close**.
8) IF "sales volume" is **high** AND "sales dynamics" is **small** AND "weight" is **heavy** THEN "distance" is **close**.

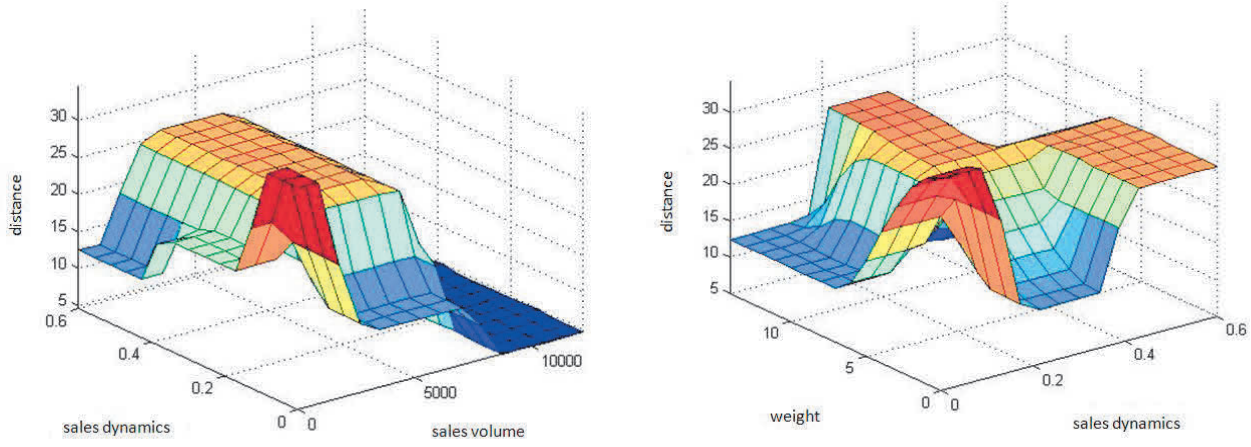

Figure 3 The influence of a) „sales volume" and „sales dynamics" on „distance"
b) „weight" and „sales dynamics" on „distance"
Source: own elaboration

As a result of the operation of the fuzzy model the values of distances in which products should be deployed in the warehouse were obtained. In the **Figure 3** we can see relationship between the "distance" and the "sales volume" / "sales dynamics" as well as the "distance" and the "sales dynamics" / "weight". The area of the warehouse with the allocation of products to the certain location that was received as a result of MS Solver tool is presented in the **Figure 4.** It was assumed that the distance between the shipping area and the rack in the warehouse cannot be greater than the value received from the fuzzy model. In this case the sum of the absolute value of the all subtractions between calculated and real value of distance was minimized as the goal function.

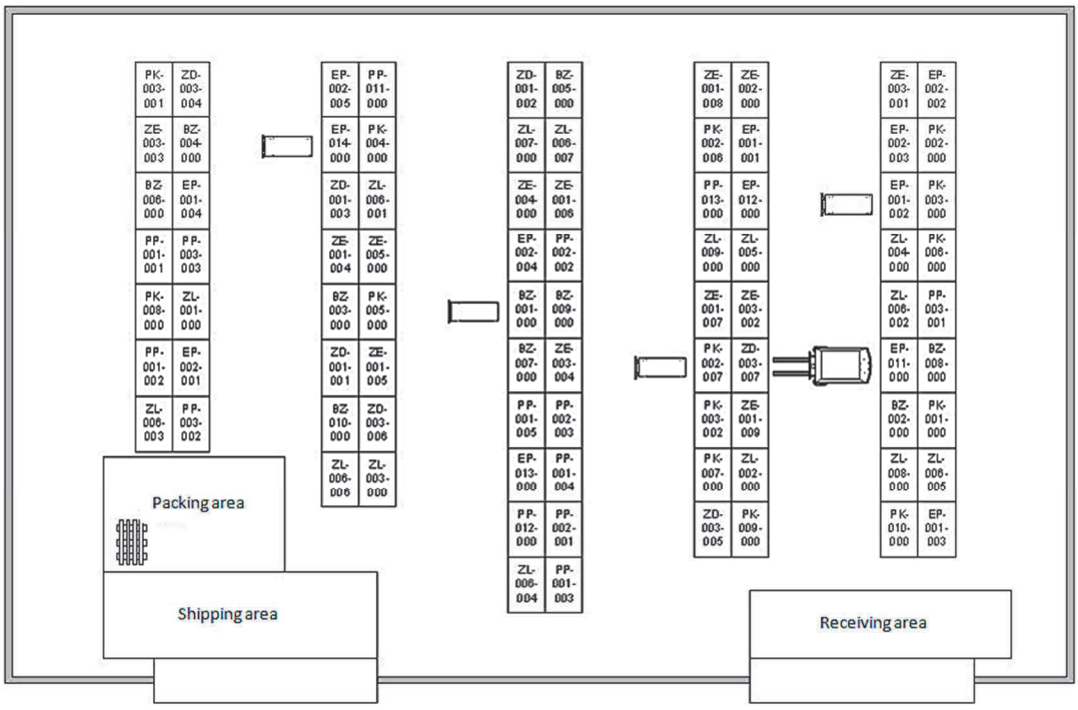

Figure 4 Conceptual plan of products allocation in the warehouse space
Source: own elaboration

5. CONCLUSION

The efficient organization of the logistic processes is crucial in creating a sustainable competitive advantage and the image of an effective enterprise among customers. The company should control all processes that are realized continuously and in the same time try to find the opportunities to deploy new improvements. Sometimes there are situations that employees are negatively oriented to any changes. The role of managers is to break the resistance of subordinates by showing the benefits which can be established in the long term. Very often, many improvements in logistics enterprises, you can enter with a zero or a small financial investment. In contrast to changes in the field of quality management, any modification to the logistic processes are aimed at simplifying material flows and the accompanying information streams. Their main purpose is to facilitate the work of people, which affects the efficiency of human resources and capital, and as a consequence brings tangible benefits for the entire enterprise.

In the decision-making processes it is extremely important to ensure the availability and authenticity of data, which are the basis for the analysis, however, the excessive amount of data can be an obstacle in the synthesis of clear and useful information. In some cases, there is no possibility of obtaining complete and reliable data. The choice of the method used to solve the problem depends on its nature and complexity. To arrange the products in the warehouse the model which is based on the fuzzy sets theory was used. This approach has made it possible to develop a plan for storage space, tailored to the requirements of the logic of completion process. It may be based on not exact knowledge of sales volume, sales dynamics and weight of the products. Presented problem is only part of the area for which the logistics management can be a practice to help in the overall streamlining of the company. In the case of other than the examined object it is possible to take into account other criteria, however, the proposed model can be easily adapted to the new conditions.

REFERENCES

[1] DRIANKOV D., HELLENDOORN H, REINFRANK M., An introduction to fuzzy control, Springer Science & Business media, 2013,

[2] LI W., CHANG X.G., WAHL F.M., JAY FARRELLC, Tracking control of a manipulator under uncertainty by FUZZY P+ID controller, Fuzzy Sets and Systems 122, 2001

[3] SOLTANPOUR, M. R., ZOLFAGHARI, B., SOLTANI, M., & KHOOBAN, M. H., Fuzzy sliding mode control design for a class of nonlinear systems with structured and unstructured uncertainties. International Journal of Innovative Computing, Information and Control, 9(7), 2013.

[4] BUKOWSKI L., MAJEWSKA K., Uogólniona teoria niezawodności - cele, możliwości, koncepcje, materiały XXXIV Zimowa Szkoła Niezawodności, Szczyrk, 2006.

[5] FELIKS J., MAJEWSKA K., Application of fuzzy logic to selection and realization of optimal maintenance tasks, w: Proceedings of the 16th International Conference on Systems Science. Vol. 2, 4-6 September 2007, Wrocław, Poland, 2007.

[6] KUMAR N., BORM J-H., KUMAR A., Reliability analysis of waste clean-up manipulator using genetic algorithms and fuzzy methodology, Computers & Operations Research 39 (2012), Elsevier Science Limited, 2012.

[7] CHING-TORNG L., MAO-JIUN J. W., Hybrid fault tree analysis using fuzzy sets, Reliability Engineering and System Safety 58 (1997), Elsevier Science Limited, 1997

[8] HUANG D., CHEN T., WANG M.J.J., A fuzzy set approach for event tree analysis. Fuzzy Sets and Systems 118, 2001.

[9] NIETO-MOROTE A., RUZ-VILA F., A fuzzy approach to construction project risk assessment, International Journal of Project Management 29 (2011), Elsevier Science Limited, 2011.

[10] AKMAN, G., & BAYNAL, K. (2014). Logistics service provider selection through an integrated fuzzy multicriteria decision making approach. Journal of Industrial Engineering, 2014.

[11] FELIX T. S. Ch. , KUMAR N. , TIWARI M.K., LAU H. C. W., CHOY K. L., Global supplier selection: a fuzzy-AHP approach, International Journal of Production Research, Vol. 46, No 14, Taylor&Francis, 2008.

[12] NOORI, S., ZANDAGAHI, A., LALI, R., & MOSTAFAVI, M. (2014). A fuzzy QFD methodology to improve logistics service. *Decision Science Letters*, *3*(3), 359-374.

[13] WOJCIECHOWSKA M., Zarządzanie gospodarką magazynową, PWE, Warszawa 1997, s.20.

[14] ZADEH L. A., Fuzzy sets, Information Control 8, 1965.

[15] KLIR G. J., YUAN B., Fuzzy sets and fuzzy logic. Theory and Applications, Prentice Hall, 1995.

[16] http://riad.usk.pk.edu.pl/~bmrozek/dydaktyka/LabFL2_ModelMamdani.pdf, (09.2016)