UNIVERSITY OF PARDUBICE

FACULTY OF TRANSPORT ENGINEERING

A DECISION-MAKING MODEL FOR THIRD-PARTY LOGISTICS PROVIDER SELECTION

DOCTORAL THESIS PRECIS

2021

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Study program

P3710 Technique and Technology in Transport and Communications

Field of study

3708V024 Technology and Management in Transport and Telecommunications

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Table of Contents

1 INTRODUCTION

In recent years, the field of logistics and supply chain management has grown in both complexity and popularity. The 3PL logistics issue has never been as actual as it is in the last decade. Due to rapid changes in technology and the quality of business processes as well, many players appearing in the complex logistics market. Most of those players collaborate with some companies that need to outsource some parts of their businesses. One of the most difficult tasks for the company who is searching for outsourcing is how to evaluate and select the best external business partner for collaboration. Nowadays, freight transport companies are faced with a large number of challenges and obstacles in the process of transporting goods from the point of origin to the point of the destination. In today's world of efficient production, companies choose a mode of transport that will bring the best value for business at the end of the process. In addition, many criteria come into consideration when the evaluation and selection are made, and depending on the needs of the companies, not all criteria are equally important. However, in addition to cost savings, many other criteria such as quality, delivery, safety are taken into consideration. By selecting the most suitable 3PL service provider, a company can greatly save on costs, improve the quality of business as well as maintain existing, and gain new customers.

The main problem in this dissertation is addressed to 3PL service provider selection. In other words, the 3PL selection problem will be considered to contribute to this very demanding field. Given the fact that the problem established is multidisciplinary by nature, it is necessary to combine knowledge from various fields. The idea of this dissertation is to propose a tool for making decisions about the 3PL provider selection, in the case when input numerical data about the criteria that characterize them are not clearly defined.

The doctoral dissertation is organized as follows: Chapter 1 is introductory and the importance as well as the actuality of the 3PL logistics issue is highlighted. An overview of the scientific literature based on the current knowledge in the field is presented in Chapter 2 and it is organized through the four main sub-chapters. In the review of the literature, the author of this dissertation identifies the criteria as well as methods used by various authors in the field to solve the 3PL selection problem. Besides, an extensive review of the literature is done for outsourcing as a part of the third-party logistics. Chapter 3 defines the main objective as well as related tasks of the doctoral dissertation. Chapter 4 deals with methods that should be used to solve the 3PL selection problem. The main contribution of the dissertation may be found in Chapter 5 where a decision-making tool for 3PL service provider selection is modeled. Before the decision-making tool is modeled, the issue about the needs for 3PL services is considered. It is of huge importance to emphasize that the proposed tool is particularly suitable for the implementation when there is no concrete numerical input data about the criteria, but they are given descriptively, through linguistic statements. Finally, Chapter 6 gives some concluding remarks as well as suggestions.

2 OVERVIEW OF CURRENT KNOWLEDGE

The main purpose of this section is to provide an extensive review of the literature on third-party logistics (3PL) as an outsourcing trend. The review is conducted to analyze the current state of:

- The definition, activities and benefits of third-party logistics
- The outsourcing logistics
- The criteria for Third-Party logistics (3PL) provider evaluation and selection
- The methods for Third-Party logistics (3PL) provider evaluation and selection

2.1 Definition, activities and benefits of third-party logistics

According to Lieb (1992), Third-Party Logistics (3PL) is using an external company to perform the logistics services, which have traditionally had performed within the organization. On the other side, Bask (2001) introduced the term of Third-Party Logistics as a relationship between interfaces in the supply chain and 3PL providers, where the logistics services are appearing, in a shorter or longer-term relationship, with an objective of effectiveness and efficiency. Banrodt and Davis (1992) simply defined Third-Party logistics as logistics outsourcing.

According to Chen and Wu (2011), Third-Party Logistics services mostly focus their attention on transportation and warehousing activities and should have professional experience in each service.

Dittmann and Vitasek (2016) emphasized that, nowadays, 3PL service providers generated a range of benefits for companies who engage them. Such benefits are as follows: reduce transport costs, improve customer satisfaction, reduce future costs by leveraging the 3PL's expertise and technology, provide global expertise, reduce risk, etc.

2.2 Review of the literature on outsourcing logistics

Outsourcing as a strategy was first adopted in the 1980s, but as a practice, it was originated in the 1950s (Hätönen and Eriksson, 2009). According to Maltz and Ellram (1997) as well as Razzaque and Sheng (1998), Third-Party Logistics (3PL) is referring to outsourcing logistics. Power et al. (2006) emphasized that the term outsourcing consists of two separate words – "out" and "sourcing", where sourcing refers to the act of transferring work, responsibilities, and decision rights to someone else. Scott-Jackson et al., (2005) as well as Sharma and Loh (2009) agreed that outsourcing was handing over one or many of the business processes to an outside vendor or the utilization of outside available services provided by third-party. At the end of this subsection, after an extensive review of the literature, it may be stated that this field has been gaining special attention in the last decades. Some basic definitions of outsourcing, advantages and disadvantages, outsourcing risks, different kinds of outsourcing problems as well as the scientific methods used in outsourcing logistics were the subject of this review.

2.3 Review of the literature based on the criteria for third-party logistics (3pl) provider evaluation and selection

Nowadays, in the field of logistics, it is difficult to find the right external business partner (3PL service provider), since the number of 3PL providers has increased significantly and continues to grow. The other reason is that there are huge amounts of criteria that characterize 3PL providers and it is not so easy to decide about its evaluation and selection. It is of huge importance to pay attention to the criteria that characterize them. Not all criteria are equally important. According to an extensive review of the literature, it may be stated what criteria were used to evaluate and select 3PL providers by various authors and which ones are the most important. Based on that information, the main idea of the doctoral dissertation is to invent and propose a model that will be easy to implement on the one hand, while on the other hand to sublimate all or at least most of the previously mentioned criteria from the source of the literature. It's been noticed that the most often used criteria are the economic, environmental, social and technical. Each of these criteria has the subcriteria.

2.4 Review of the literature based on the methods for third-party logistics (3PL) provider evaluation and selection

The 3PL service provider evaluation and selection is not so easy task for decision-makers, given the fact that multiple criteria as well as many existing methods ought to be taken into consideration. From the early beginning until now, the researchers have evolved many methods to solve the 3PL evaluation and selection problem. Most of the methods belong to multi-criteria decision-making methods. In addition to multi-criteria analysis methods, many other methods, such as statistical, mathematical programming methods as well as integrated approaches are used.

3 THE MAIN OBJECTIVE OF THE DISSERTATION

The 3PL selection problem is an actual issue nowadays. Bearing that fact in mind, it is necessary to contribute to this field by inventing a decision-making tool for 3PL provider selection. The main objective of the doctoral dissertation is to propose a decision-making tool that can help decide about the 3PL service provider selection. That kind of tool is supposed to be understandable as well as easy for implementation.

The intention of this tool is to help decide about the best 3PL provider solution in the circumstances when there is no precise information about input values related to the criteria or they cannot be expressed as crisp values. The novelty of the thesis is its ranking of the 3PL service providers on the economic, safety, environmental, technological, and social dimensions that is of crucial importance for the sustainability of the logistics industry and global society.

In order to fulfill the objective of the research, it is necessary:

- to analyze the current situation in the field of third-party logistics (3PL),
- to determine the possibility of improvement in the field of 3PL evaluation and selection.
- to develop a new preference model for the 3PL provider selection
- to apply the proposed model to the illustrative example

In order to be effectively accomplished the complex tasks highlighted in the doctoral thesis, it is necessary to apply the knowledge from a number of different areas, given the fact that the problem is multidisciplinary. These areas cover logistics theory, fuzzy logic theory, multi-criteria decision-making, programming, and some parts of operational research.

4 OVERVIEW OF THE METHODS USED IN THE DISSERTATION

This chapter provides an insight into the methods used in the dissertation. Given the fact that the 3PL selection problem needs to take into consideration multiple criteria, the multi-criteria analysis methods combined with fuzzy logic are used. Such methods are Additive Ratio Assessment (ARAS) method (Zavadskas and Turskis, 2010), TOPSIS method (Hwang and Yoon, 1981), Analytic Hierarchy Process (AHP) (Saaty, 1980), method for consistency checking, fuzzy logic (Zadeh, 1965), Wang-Mendel's method (Wang & Mendel, 1992) as well as FUZZY-AHP method (Kwang and Bai, 2002).

5 A PROPOSAL OF A DECISION-MAKING TOOL IN THIRD-PARTY LOGISTICS (3PL) PROVIDER SELECTION – ILLUSTRATIVE EXAMPLE

In this chapter, a decision-making tool in third-party logistics (3PL) provider selection is proposed and applied to the illustrative example. The schematic representation of the methods used in the dissertation is depicted in Figure 1.

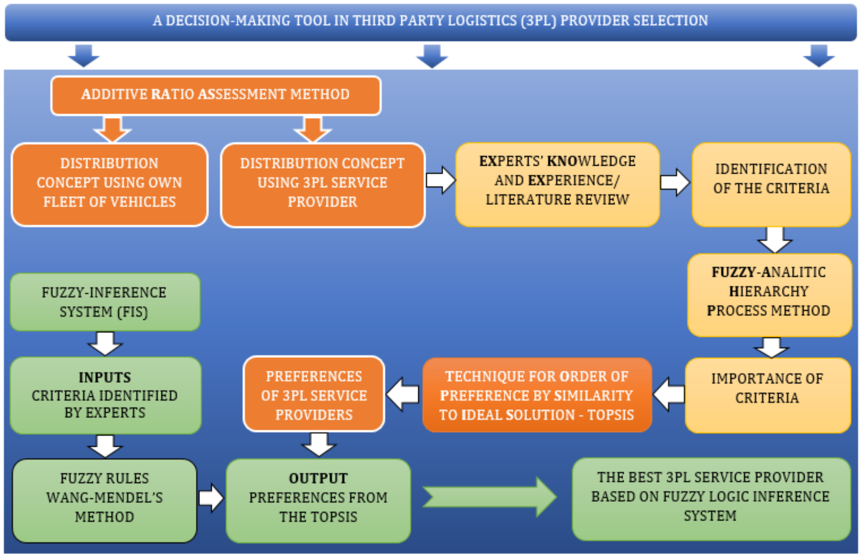

Figure 1. A decision-making tool for 3PL service provider selection (author)

The first phase of the methodology is to define as well as solve a distribution-concept selection problem. In other words, it is necessary to find out whether the company needs 3PL services for distribution purposes or its fleet of vehicles might organize the distribution. Before the methodology is applied to this kind of problem, the experts' opinions are included to define as well as assess the criteria/sub-criteria. After the criteria are identified and assessed, the Additive Ratio ASsessment (ARAS) method has been applied to find the best distribution concept. Two possible scenarios should be obtained by the ARAS method. The distribution concept by own fleet of vehicles and the distribution concept using the 3PL service providers. When the distribution concept is established, it is necessary to explain the further phase of the methodology proposed. For the case where the second alternative is the best solution, it is of huge importance to know how to evaluate and select the best 3PL service provider for collaboration.

The second-phase starts by identifying the criteria for the 3PL provider evaluation and selection as well as determining its importance. For the criteria identification, an extensive review of the scientific literature, as well as experts' opinions are taken into consideration. To obtain an influential relationship between criteria (criteria weights), the Fuzzy-AHP method is used.

The obtained criteria weights are further used in the third phase where the TOPSIS method is applied. The TOPSIS method is used to rank the 3PL service provider among 25 of them.

The final phase is the main contribution of the doctoral dissertation. Namely, in this phase, a decision-making tool for 3PL provider selection is proposed. This kind of tool uses the criteria identified in the second phase as the inputs, while the results from the TOPSIS are utilized as an output. To obtain the fuzzy rule base, Wang-Mendel's method is applied. The proposed tool is particularly suitable for the implementation when there is no concrete numerical input data about the criteria, but they are given descriptively, through linguistic statements.

5.1 Distribution concept selection problem via ARAS MCDM method

The ARAS method is applied to the distribution concept selection problem based on the idea from a tire manufacturing company in the Czech Republic. Two possible alternatives as distribution concepts are considered. The first one (Alternative 1) relates to the distribution concept by its own fleet of vehicles. On the other side, the second distribution concept (Alternative 2) relates to engaging the 3PL service provider. The hierarchical structure of the distribution concept selection is shown in Figure 2.

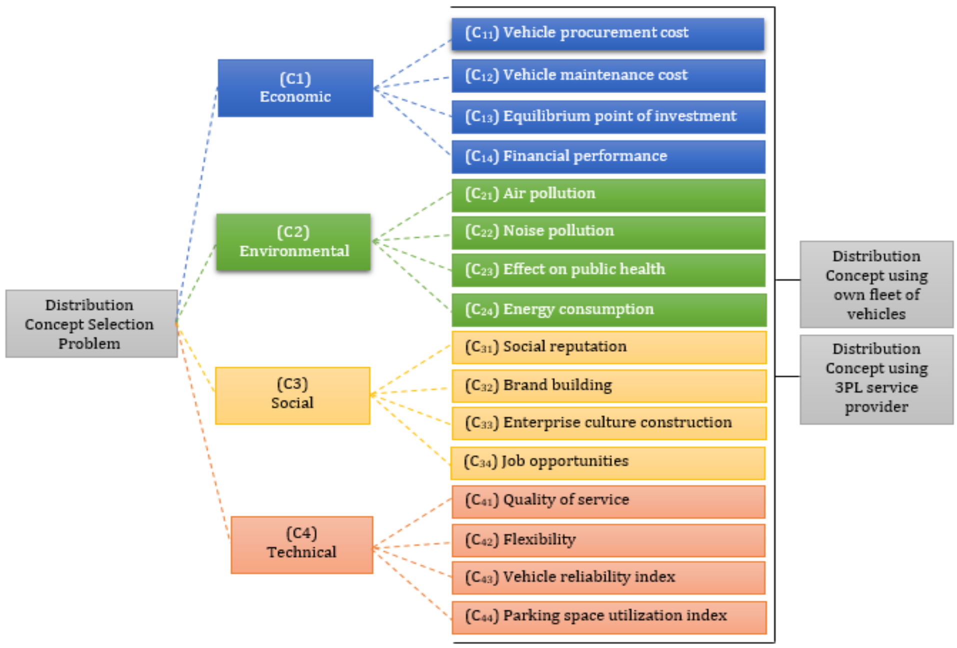

Figure 2. A hierarchical structure of the distribution-concept selection problem (author)

Based on the ARAS method, the second alternative is shown as better solution for the distribution concept, participating with 0.92 when compares with the first alternative (0.83). To confirm the second alternative as the best one, the topsis method is applied and the results show that the alternative 2 participates with 0.60 (as better one) while the alternative 1 is 0.39. After deciding about the distribution concept, the next phase of the aforementioned methodology is to help decide on 3PL assessment and selection.

5.2 A Fuzzy-AHP approach to estimate the influential relationship between the evaluation criteria for 3pl service provider selection

In this sub-section, before applying the TOPSIS method, it is necessary to identify the criteria and determine the influential relationship between them. The influential relationship between criteria is solved by the Fuzzy-AHP method (Figure 3).

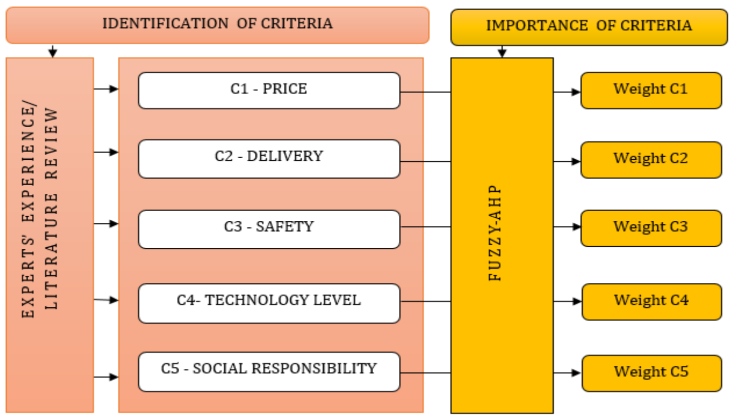

Figure 3. Identification and assessment of criteria for 3PL selection (author)

The biggest importance, 0.5148 is assigned to the price. After that, the criterion of delivery is in the second place by the importance 0.2111, safety participates with 0.1951, while, technology level and social responsibility are determined as lesser important with 0.047 and 0.031 respectively.

5.3 Application of the TOPSIS methodology for the selection of a 3PL service provider

The TOPSIS methodology is a very reliable tool in determining the preferences of 3PL service providers. In this dissertation, this method is used to select an appropriate 3PL service provider. Twenty-five 3PL service providers are compared and evaluated. The best possible solution is the best preference for 3PL, according to price, delivery, safety, level of technology, and social responsibility.

Since no complete data were available to create a real-life case study, given the time constraints of this research, some hypothetical data have been used within this dissertation. The data for 3PL providers are usually as a rule privately owned. Moreover, some data are not freely available to the general public or the scientific community, probably due to a corporate policy to protect proprietary information. However, the input data for twenty-five 3PL service providers are formulated based on interviews with experts from the Czech Republic and Poland. The experts interviewed belong to the logistics field. The interviewed practitioners confirmed that the illustrative example, generated by the author of the dissertation, was close to the real conditions on the market. Therefore, the purpose of research was to show the applicability of the proposed methodology, especially when a larger sample is considered. Since this is an academic study, the stress is placed on the methodological issue. However, the TOPSIS as well as the methodology based on Fuzzy Inference System (FIS) is general and can be applied in reality to any other logistics company that considers the possibility of employing 3PL providers. Future research will surely address this topic to overcome this limitation and apply the proposed methodology to the real-life study. The obtained results by the TOPSIS method are depicted in Figure 4.

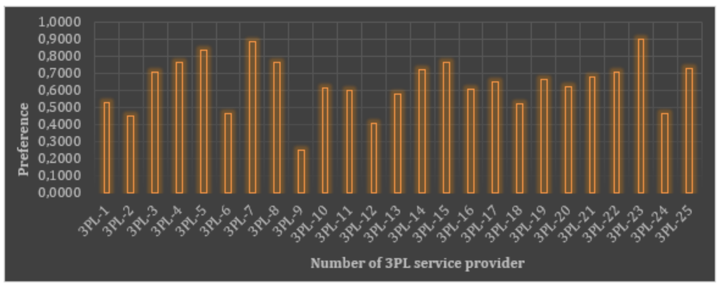

Figure 4. Final rank of 3PL providers (author)

5.4 The proposal of fuzzy model for 3PL provider selection based on empirical data

In this sub-section, the main contribution of this dissertation may be found. A fuzzy inference system (FIS) is developed for selecting a third-party logistics provider (Figure 5).

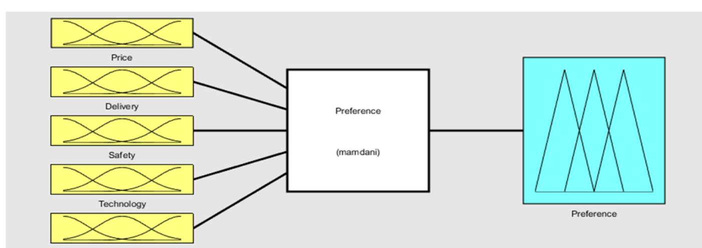

Figure 5. The proposal of fuzzy model for 3PL selection (author)

The proposed FIS is designed by using the empirical data, which are obtained in the previous part of this dissertation. The considered criteria, price, delivery, safety, technology level, and social responsibility are taken as input variables. The output variable is a preference for the 3PL provider. The FIS is based on Wang-Mendel ‘s method for determining fuzzy rules. The fuzzy rules are essential for the design of FIS and by that for forming a decision-making tool for 3PL selection. There is a possibility to implement the interval type-2 fuzzy sets for the same purpose (Senturk et al. 2017, Ghorabaee et al. 2017); however, in this case, the type 1 fuzzy system achieved satisfactory results.

5.4.1 Input and output variables

The first input variable is the price and it is described by three fuzzy sets: Low price (LP), Medium price (MP), and High price (HP). As for the price, the upper and lower limits are set for all other criteria as well as the average values. This is done by analyzing the empirical data collected by the author of this dissertation. It is supposed, according to empirical data that the price is low if the 3PL service provider provides transport service between 83.32 and 94.8 Euro-Cent per km. The price is medium (MP) if the 3PL service provider requests the costs for transport service between 91 and 98 Euro-Cent per km. The price is high (HP) if the transport costs are between 94.8 and 106 Euro-Cent per km. Similarly, all the other variables are defined based on the collected data. The descriptive statistics of the sample are shown in Table 1. Consequently, the input-output variables are designed as shown in Figure 6 to Figure 11.

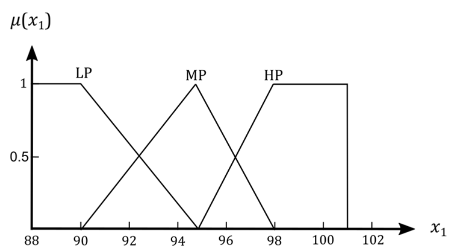

Figure 6. The first input variable – "Price" described by membership functions (author)

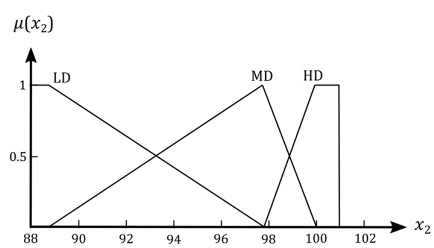

Figure 7. The second input variable – "Delivery" described by membership functions (author)

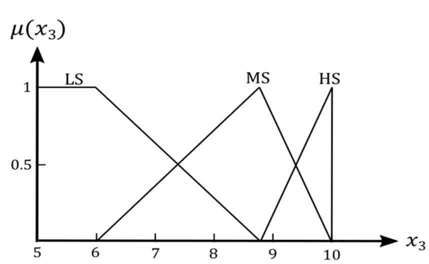

Figure 8. The third input variable – "Safety" described by membership functions (author)

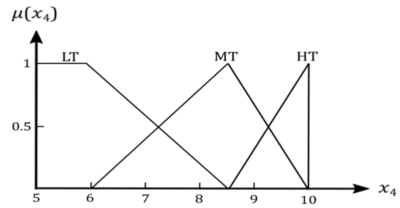

Figure 9. The fourth input variable – "Technology level" described by membership functions (author)

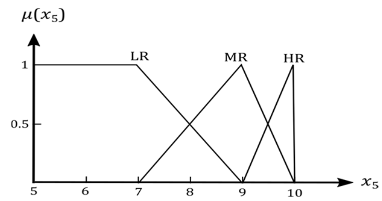

Figure 10. The fifth input variable – "Social responsibility" described by membership functions (author)

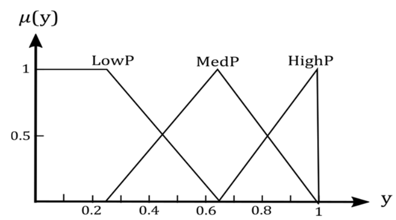

Figure 11. The output variable – "Preference" described by membership functions (author)

Table 1. Descriptive statistics of the sampe (author)

Input Variable	Domain	Sample		
		min	max	average
x_1- Price	[88-101]	90	98	94.80
x_2-Delivery	[88-101]	88.85	99.98	97.90
x_3-Safety	[5-10]	6	10	8.92
x_4-Technology level	[5-10]	6	10	8.56
x_5-Social Responsibility	[5-10]	7	10	9
y-Output variable The preference for 3PL	[0-1]	0.25	0.90	0.64

5.4.2 Determining the fuzzy rules based on Wang-Mendel's method

In the continuation of the dissertation, the author used a well-known method, which combines both numerical data and expert opinion for the design of fuzzy rules. Wang-Mendel's method, characterized by 5 steps (Wang and Mendel, 1992), is implemented:

The first step divides the input and output spaces into fuzzy regions. The second step generates fuzzy rules from the given data pairs. The third step assigns a degree to each rule. Since there are usually lots of data pairs and each data pair generates one rule there will probably be some rules, so-called conflicting rules that have the same „if" part, but a different „then" part. Based on the calculated degree of each rule, which is obtained by implementing the appropriate programming code, the non-conflict fuzzy rules that form the final rule database is selected. The fourth step creates a combined fuzzy rule database, on both the linguistic rules of a human expert and the generated rules from data. Finally, the last step determines a mapping based on the combined fuzzy rule base using a de-fuzzifying procedure.

A set of input-output data pairs is formulated:

$x_1{}^{(1)}\ x_2{}^{(1)}\ x_3{}^{(1)}\ x_4{}^{(1)}\ x_5{}^{(1)}\ y^{(1)}$

$x_1{}^{(2)}\ x_2{}^{(2)}\ x_3{}^{(2)}\ x_4{}^{(2)}\ x_5{}^{(2)}\ y^{(2)}$

… … … … …

$x_1{}^{(25)}\ x_2{}^{(25)}\ x_3{}^{(25)}\ x_4{}^{(25)}\ x_5{}^{(25)}\ y^{(25)}$ (1)

x_1, x_2, x_3, x_4, and x_5 (x_1– price, x_2 – delivery, x_3 – safety, x_4 – a level of technology, x_5 – social responsibility) are taken as inputs in the FIS. Y represents an output of the system (a preference for 3PL service provider). The numbers in brackets represent the exact 3PL provider. This is a five-input, one-output case. The task is to generate a set of fuzzy rules from the collected input-output data pairs and use these fuzzy rules to determine a mapping (x_1, x_2, x_3, x_4, x_5) -> y

Step 1. Divide the input and output spaces into fuzzy regions

According to the empirical data the domain intervals of x_1, x_2, x_3, x_4, x_5 and y are set up as: [x_1^- - x_1^+], [x_2^- - x_2^+], [x_3^- - x_3^+], [x_4^- - x_4^+], [x_5^- - x_5^+], [y^- - y^+], where "domain interval" of variable means that most probably the values of this variable will be in the set interval. Each domain interval should be divided into 2N+1 regions. In this case, each variable is defined by three regions: L (Low), M (Medium), and H (High).

A fuzzy membership function is assigned to each region, which is done based on data shown in Table 1. Figure 6 – Figure 11 present the domain intervals from x_1 to x_5 respectively, divided into three regions (fuzzy sets) and the domain interval of an output variable y is divided into three regions as well. The shape of each membership function is triangular. Even though the shapes of membership functions may be different, it is not expected that this should change the results significantly.

Step 2. Generate Fuzzy Rules from Given Data Pairs

In this step, the degrees of given x_1(i), x_2(i), x_3(i), x_4(i), x_5(i) and y(i) in different regions are determined, and the regions with the maximum degree are selected. For example, in the case of 10th 3PL provider, x_1(10)=97 cents. This value has a degree equal to 0.3125 in MP and degree 0.6875 in HP. The remaining region is not considered since its degree is equal to zero. The value of membership degrees for all variables in the case of the 10th 3PL provider has presented in Table 2.

Table 2. The membership degrees of regions for 3PL number 10 (author)

	Degree for $x_1^{(10)}$=97	Degree for $x_2^{(10)}$=99.23	Degree for $x_3^{(10)}$=9	Degree for $x_4^{(10)}$=9	Degree for $x_5^{(10)}$=9	Degree for $y^{(10)}$= 0.7692
Low	0	0	0	0	0.1304	0
Medium	0.3125	0.3275	0.8333	0.6897	0.8696	0.4817
High	0.6875	0.6725	0.1667	0.3103	0	0.5183

Based on the obtained values of degrees where the maximum degrees are bolded, the following fuzzy rule may be formed:

IF $\boldsymbol{x_1}$ is ***High Price (HP)*** and $\boldsymbol{x_2}$ is ***High Delivery (HD)*** and $\boldsymbol{x_3}$ is ***Medium Safety (MD)*** and $\boldsymbol{x_4}$ is ***Medium Technology (MT)*** and $\boldsymbol{x_5}$ is ***Medium Responsibility (MR)***, THEN $\boldsymbol{y}$ is ***High Preference (HighP)***.

This procedure is performed for all remaining 3PL providers from the sample; therefore, the 19 fuzzy rules are obtained.

Step 3. Elimination of the same or conflict rules

The purpose of this step is to form a fuzzy rule base containing just rules from empirical data that are not conflicting or the same. The conflict rules have the same IF part, but a different THEN part. To resolve this, the degree of each rule – D(i) should be calculated, for the case when a rule is defined as follows: "IF x_1 is A and x_2 is B and x_3 is C and x_4 is D and x_5 is E THEN y is F".

$$D(i) = \mu_A(x_1) \cdot \mu_B(x_2) \cdot \mu_C(x_3) \cdot \mu_D(x_4) \cdot \mu_E(x_5) \cdot \mu_F(y) \tag{2}$$

$D(i)$ is a degree of i-th rule $\mu_A(x_1)$, is a value of membership function of the region A when the input value is x_1, etc. In a conflict group, only the rule that has a maximum degree may be accepted. In this case, the 19 rules from empirical data in the final fuzzy rule base are obtained, which is shown in Table 3.

Step 4. Design of combined fuzzy rule base

The final fuzzy rule base should consist of 243 fuzzy rules. Besides previously mentioned 19 rules that are obtained based on empirical data, the remaining rules are generated based on expert opinion. In this process, the following logic is implemented: if the price of service is higher, then the preference for selection of an observed 3PL provider is lower; if delivery is higher, then the preference is higher; if safety is higher, then the preference is higher; if a technology level is higher, then the preference is higher and if social responsibility is higher, then the preference is higher.

Table 3. The Fuzzy-rules based on Wang-Mendel (author)

D(i)	Serial number of $\mu_A(x_1)$	Serial number of $\mu_B(x_2)$	Serial number of $\mu_C(x_3)$	Serial number of $\mu_D(x_4)$	Serial number of $\mu_E(x_5)$	Serial number of $\mu_F(y)$
0.1414	1.0000	2.0000	3.0000	2.0000	2.0000	3.0000
0.0467	1.0000	3.0000	1.0000	2.0000	2.0000	1.0000
0.2876	1.0000	3.0000	2.0000	3.0000	3.0000	2.0000
0.6477	1.0000	3.0000	3.0000	2.0000	2.0000	3.0000
0.2982	2.0000	1.0000	2.0000	1.0000	1.0000	2.0000
0.4308	2.0000	1.0000	2.0000	2.0000	2.0000	2.0000
0.2693	2.0000	2.0000	2.0000	1.0000	1.0000	2.0000
0.1570	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000
0.6032	2.0000	2.0000	3.0000	1.0000	1.0000	2.0000
0.3856	2.0000	2.0000	3.0000	3.0000	3.0000	2.0000
0.2914	2.0000	3.0000	2.0000	2.0000	2.0000	2.0000
0.4556	2.0000	3.0000	2.0000	3.0000	3.0000	2.0000
0.2719	2.0000	3.0000	3.0000	2.0000	2.0000	3.0000
0.1600	3.0000	2.0000	2.0000	2.0000	2.0000	2.0000
0.1990	3.0000	2.0000	2.0000	3.0000	3.0000	2.0000
0.3446	3.0000	2.0000	3.0000	2.0000	2.0000	2.0000
0.8846	3.0000	3.0000	1.0000	3.0000	3.0000	1.0000
0.2535	3.0000	3.0000	2.0000	2.0000	2.0000	2.0000
0.2583	3.0000	3.0000	3.0000	1.0000	1.0000	2.0000

Step 5. Determine a mapping based on the combined fuzzy rule base

In this step, the proposed FIS is tested and the obtained results are given in Table 4.

To compare the results of FIS and preferences obtained by the TOPSIS the Cumulative Error (CE) is calculated according to equation (3) (Čubranić-Dobrodolac et al., 2019).

$$CE = \sum_{i=1}^{25} \left| y^{(i)} - Preference(i) \right| \quad (3)$$

where: CE represents a Cumulative Error in description of data, $y^{(i)}$ is the preference, calculated by the TOPSIS and $Preference(i)$ is the result of FIS.

The value CE may be used to compare the proposed FIS and some other which would be defined based on some other principles. The smaller value of CE indicates a better matching between the empirical data and FIS. A comparison of the results from this research obtained by TOPSIS and FIS is shown in Figure 12. By analyzing Figure 12, it is possible to conclude that the proposed FIS gives similar results to TOPSIS, but at the same time, the best solution is obtained according to both of the methods; however, there is a possibility for the improvement of this FIS structure. The statement is based on the fact that, in this empirical case, the best ranking 3PL service provider is not totally the same in two proposed decision-making techniques.

The explanation for this discrepancy may be found in Table 4, where the highest deviation is 0.3643. An optimization of FIS structure can be done in various ways and in this dissertation; the effects of change in shapes of membership functions are tested.

Table 4. Testing of FIS (author)

The result obtained by the TOPSIS method	The result obtained by the fuzzy system with 243 rules	Cumulative Error – CE
0.5268	0.5862	0.0594
0.4543	0.6380	0.1837
0.7061	0.6207	0.0854
0.7689	0.7232	0.0456
0.8375	0.4867	0.3508
0.4653	0.5037	0.0385
0.8868	0.7214	0.1654
0.7638	0.4991	0.2647
0.2501	0.4082	0.1580
0.6172	0.5975	0.0197
0.6027	0.6208	0.0181
0.4072	0.4082	0.0010
0.5764	0.4510	0.1254
0.7206	0.5939	0.1267
0.7677	0.6112	0.1566
0.6083	0.7209	0.1126
0.6505	0.5982	0.0523
0.5240	0.4550	0.0689
0.6649	0.5880	0.0769
0.6216	0.6488	0.0272
0.6820	0.5173	0.1647
0.7065	0.4206	0.2859
0.9011	0.7557	0.1453
0.4663	0.5823	0.1159
0.7285	0.3642	0.3643
		∑ = 3.2130

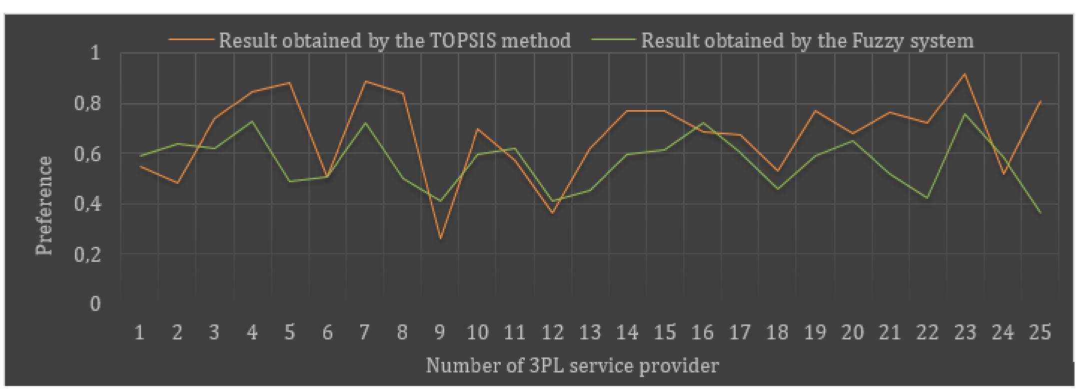

Figure 12. Comparison of the results obtained by TOPSIS and FIS

5.4.3 Sensitivity analysis of the proposed fuzzy model based on change in shapes of membership functions

In the case of triangular membership functions, the value of CE is equal to 3.2130. This value of CE is further compared with other FIS structures where the shapes of membership functions are changed. Additionally, the testing of different FIS structures may be seen as a starting point in the optimization of FIS structure in pursuance of achieving the same conclusion about the best 3PL provider as in the case of TOPSIS. The results of testing may be found in Table 5.

Table 5. Stability testing of FIS structures and comparing of CE values (author)

Shape of membership function	CE	Serial number of chosen 3PL service provider
Triangular – trimf	3.2130	3PL-23
Trapezoidal – trapmf	3.2242	3PL-23
Generalized bell-shaped – gbellmf	3.0784	3PL-7
Gaussian – gaussmf	3.5385	3PL-23
Gaussian combination – gauss2mf	3.1442	3PL-23
zmf, pimf, smf	3.0855	3PL-23

The conclusion of the testing procedure related to changing the shape of membership functions is that there are no differences in the best 3PL service provider. The only exception is in the case of the generalized bell-shaped membership function, where the cumulative error is equal to 3.0784. When it comes to the empirical implementation of the proposed models, in the case of crisp input values, the TOPSIS should be used, while in the case of imprecise input data, the proposed FIS structure is a convenient choice.

6 CONCLUSION AND FUTURE RESEARCH DIRECTIONS

The dissertation has addressed the 3PL provider selection problem. To assist in decision-making, the implementation of fuzzy logic combined with the multi-criteria analysis methods is proposed. The main problem is divided into four phases and the following results were obtained:

In the first phase, a distribution-concept selection problem is considered; In other words, it was necessary to decide whether the company needs to invest in its own fleet of vehicles or to engage the 3PL service provider. By applying the ARAS multi-criteria decision-making method and taking into consideration the economic, environmental, social as well as technical criterion, it was established that the distribution concept using 3PL service providers (Alternative 2 = 0.929) is a better solution for the company who considers distribution activities. The same alternative is confirmed as a better one by applying the TOPSIS method, with the preference of 0.6088. After deciding about the distribution concept, the second phase has considered the 3PL provider evaluation and selection problem.

The second-phase started by identifying the criteria for the 3PL provider evaluation and selection as well as determining its importance. To identify the criteria, an extensive review of the scientific literature, as well as experts' opinions are taken into consideration. To obtain an influential relationship between criteria, the Fuzzy-AHP method is used. At the end of the second phase of the model, the following conclusion was reached: five criteria such as price, delivery, safety, technology level, and social responsibility were established and their importance is obtained. The highest importance is assigned to the price (0.5148). The second place by importance is assigned to delivery (0.1211). The criterion of safety was at third place (0.1951), while the technology level (0.0470), as well as social responsibility (0.0310) were evaluated with less importance. The obtained criteria weights are further used in the third phase, where the TOPSIS method is applied.

The TOPSIS method was used to rank the 3PL service providers among 25 of them. As a result of the TOPSIS method, it was shown that the 3PL-23 was the best possible alternative with the preference of 0.9011. After the sensitivity analysis was conducted on the TOPSIS, it was concluded that the most stable criteria are price, delivery, and technology level.

The main contribution of the doctoral dissertation (besides the first phase) may be found in the fourth phase. In this phase, a decision-making tool for 3PL provider selection is designed as a FIS structure, where inputs are the previously defined criteria (price, delivery, safety, technology and social responsibility) and output is a preference for 3PL selection. The fuzzy rules are generated based on the collected empirical data, preferences obtained by the TOPSIS method and expert opinion using Wang-Mendel's method. The proposed tool is particularly suitable when input data are not crisp values, but they are given descriptively through the linguistic statements. The result of the proposed FIS showed the 3PL-23 as the best possible alternative.

When it comes to the final results, it may be concluded that both methods, the TOPSIS method, and the Fuzzy Inference System (FIS) gave the same results. However, the main advantage of the methodology proposed in the dissertation reflects the fact that preferences for choosing the best alternative can be obtained based on insufficiently precise input data, i.e. input data are given throughout linguistic statements within given numerical intervals. Unlike the proposed methodology, the TOPSIS method only shows the results of the crisp input values of the criteria.

Therefore, the proposed FIS structure may be implemented in practice, particularly in the case where there is no concrete numerical input data, but they are, partially or completely, given descriptively, through linguistic statements. In the case of crisp input values, the implementation of TOPSIS would be sufficient. The introduced decision-making tool could have widespread usage in all related MCDM logistics problems.

There are two practical as well as two methodological contributions in the dissertation field. When it comes to practical contributions, the Freight Distribution Concept (FDC) Selection in terms of outsourcing (need for 3PL service providers) is provided and can help the company to make a decision. The second practical contribution is related to the Third-Party Logistics (3PL) provider evaluation and selection process.

Regarding the methodological contribution, the two most important ones can be pointed out: 1) for the first time, the ARAS method is applied to solve the Freight Distribution Concept (FDC) selection problem in the field of 3PL logistics. The main advantage of the ARAS method for the FDC selection problem reflects the fact that it can help us decide about the needs for the 3PL services; 2) the original fuzzy logic methodology is proposed to solve the 3PL evaluation and selection problem.

In the end, it may be concluded that the individual tasks of the main objective of the dissertation were completed. Such tasks were: 1) to analyze the current situation in the field of third-party logistics (3PL); 2) to determine the possibility of improvement in the field of 3PL evaluation and selection; 3) to develop a new preference model for the 3PL provider selection.

When it comes to the future research, there are the following directions: 1) to adjust the proposed FIS by optimizing it through minimizing the cumulative error in describing the empirical data and by harmonizing the final decision with TOPSIS; 2) to test the proposed methodology on different samples would be of particular interest; 3) to overcome the limitation of the application of the methodology to the illustrative example, it will be of particular interest to apply the proposed methodology to the real-life study; 4) to adjust the methodology in the picture fuzzy environment; 5) to compare the proposed methodology with the other multi-criteria decision-making methods.

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