Third Party Logistics Service Selection using Fuzzy Multiple Attribute Decision – Making System

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This study models the selection of third party logistics service provider (3PL) process considering comprehensive criteria and fuzzy nature of such problems. Criteria are identified and selected with respect to various aspects of logistics management, and existing vagueness in their behaviours and their relational preferences. Multiple attribute decision–making (MADM) approach and fuzzy methodology are applied. Based on a wide review of previous research, a fuzzy MADAM (FMADM) procedure is developed. Accordingly, especial algorithm in applying FMADM to 3PL selection problems is defined. A numerical example supports the developed procedure. Then, a real-world case study is explained and its 3PL selection problem is discussed. Results show reliability and efficiency of the model.

1. INTRODUCTION

Cost reduction pressures together with a more emphasis on maximising the return on assets have pushed organisations to focus on the core competences that provide them with competitive advantage. This leads organisations to limit their internal processes and pass the non-core processes to suppliers, contractors, or service providers. Logistics, for many organisations, is a non-core operation. Accordingly, a wide range of logistics activities, such as delivery, shipment, warehousing is handled by external companies. The form and performance of outsourcing logistics may vary in different business sectors.

Third-party logistics (3PL) is generally referred to external providers of transport and logistics services, which have traditionally been performed internally (Coyle et al., 2003). The scope of the 3PL's operations can be limited to a selected transport or warehousing activities, or can be broadened to entire logistics or even production processes and supply chain management. Warehousing and transport together with associated documentation services have been provided by 3PLs for years. However, an expanding range of services, such as final assembly of products, packaging, labelling, unpacking, inventory control, order fulfilment, reverse logistics, and product tracking and tracing are added to the 3PL services these days (Browne et al., 2007). 3PLs indeed try to offer a wider and more customised range of logistics services, to provide a higher value to their clients and competitive advantages for the whole supply chain. Besides, working with 3PL gives a firm access to multi-modal transport system, multiple distribution channels, higher flexibility, and lower cost (Trentin, 2011).

Today, logistics service providers need to be flexible and quick response to the frequent changes in market and increasing uncertainties in many business sectors. They also need to work in new business models and structures where products bypass traditional distribution channels and are shipped directly to the customer's home address. Furthermore, the growth and globalisation of economies significantly depend on effective and efficient management of material flow in both supply chain upstream and downstream, where logistics play a crucial role. Logistics service providers are required to manage storage and transport resources properly to ensure the availability of raw material for manufacturing firms, semi-finished items for assembly shops, and finished products for wholesalers, retailers and consumers. Additionally, some industries expect logistics service providers to take care of product quality, inventory control, or returned items.

In recent years, the number of studies on theoretical and practical aspects of 3PL operations has been significantly increased (Marasco, 2008). The role of information technology in 3PL operations and communicating with 3PL (Evangelista and Sweeney, 2006), the impact of organisational structure and culture on working with 3PL (House and Stank, 2001), relationship management (Voss, 2003), and 3PL selection (Vaidyanathan, 2005) are the major areas which have been addressed in the recent literature on 3PL. Among them, this paper focuses on 3PL selection, which is still in need of further research. The selection of an appropriate 3PL can considerably reduce the purchasing, distribution or even production costs. This ultimately contributes to the supply chain's competitiveness, as these days supply chains compete not individual firms (Christopher, 2000). In view of that, 3PL selection can be one of the most important tasks of logistics or purchasing departments.

Supply chains may have different expectations from 3PLs. Accordingly, they set various evaluation criteria for 3PL selection. Delivery time and reliability (Spencer et al., 1994), cost (Varila, 2007), service variety, service quality (Saura, 2008), and flexibility (Chan et al., 2009) are some of the major 3PL selection criteria addressed in the literature.

The selection criteria are needed to be considered and analysed by decision–making models or systems. Hwang and Yoon (1981) describe, decision–making models and systems can be categorized into two main areas: (*i*) Multiple Attribute Decision–making (MADM) and (*ii*) Multiple Objective Decision–making (MODM). When decision alternatives are predetermined, the decision–making problem is MADM type. In MODM models, the solution of the problem that contains feasible and optimum (if possible) alternatives should be determined by the decision maker.

In 3PL selection, MADM models are more effective, as they work on rating and/or ranking a set of pre-determined options. Diverse criteria and several parameters should be considered in 3PL selection. These criteria and parameters are not always clear and precise. For example flexibility or service quality are not deterministic in nature. To consider this vagueness characteristic of the decision–making process in 3PL selection, this paper applies fuzzy sets theory and its concepts in developing and discussing the MADM model for 3PL selection (see Chen and Hwang 1992, Zhu et al., 2008,). Hence, a fuzzy MADM (FMADM) model is developed and discussed.

In this due, first in next section, the structure of the problem is explained and the 3PL selection model will be developed. Then, the case study is described and its 3PL selection problem is solved using the developed model. Finally, the last section rounds off with conclusions and implications for future research and practice.

2. PROCEDURE OF DECISION-MAKING

In this section, 3PL selection problem, when there are several alternatives to choose, are explained. Available alternatives are evaluated considering several criteria or attributes in effect.

The procedure of solving a multiple attribute problem in logistics management could be explained as follows. First, alternative 3PLs should be identified. Each alternative is a 3PL company with a clear, measurable performance record. Usually, an initial review should be made to check if the alternatives (i.e. 3PLs) can meet the minimum basic requirements. Basic requirements can include financial stability, resource availability, labour skills, and logistics network coverage. In some more complicated problems, decision maker may need solving a multiple objective problem to find input alternatives for the MADM model first.

After identification of alternatives, attributes should be introduced. Since, alternatives are to be assessed according to the attributes, comprehensiveness and validity of attributes are key factors in choosing them. In logistics management, the most critical attributes are speed of the service, coverage of the service locally, coverage of the service globally, price, flexibility, variety of the service, knowledge of logistics management, warehouse locations, workforce knowledge of logistics operations, availability of multi-modal transport services, and access to production resources (e.g. manufacturing, assembly and packaging).

It is notable to state that some attributes can be measured accurately and exactly, while some of them have qualitative or fuzzy nature. To handle the second group of attributes, their real characteristics should be considered. Furthermore, all attributes are not always same as each other. As a matter of fact, some are more important, and some are less important. To illustrate the relatively importance of attributes, they are assigned by weights which could be also accurate (i.e. crisp) or fuzzy.

After clearance of alternatives and attributes, the comparison and ranking procedure should be determined. During past three decades, several methods have been developed in this area (Hwang and Yoon 1981, Chen and Hwang 1992, Modarres and Saadinejad 2001). Zimmemann (1996) proposed a two-phase process in solving these problems. His process while concentrating on fuzzy multiple attributes decision–making, consists of two main models: rating model, and ranking model. In rating model, each alternative gains a value with respect to its condition under attributes.

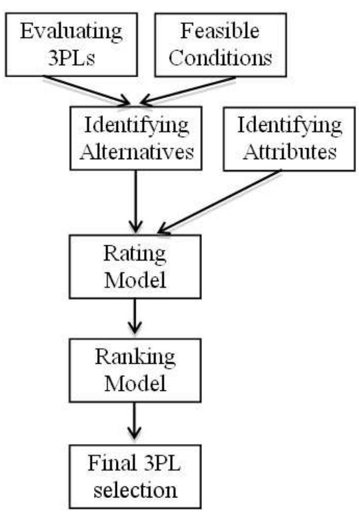

Figure 1: Flow-chart of 3PL selection procedure via MADM

While the model is fuzzy, those values are shown in the form of utility function. Next, there are some values, which should be ranked via the ranking model. In deterministic environment, the ranking process is straightforward. However, ranking utility functions, which are actually fuzzy numbers, should follow a different model and procedure. The rank of alternatives, which is the result of ranking model is the final solution of multiple attribute decision–making. The step–by–step procedure of selecting the best alternatives of 3PLs is shown in figure 1. In the following sub-section, each step of the above proceduress will be explained.

2.1. ALTERNATIVES AND ATTRIBUTES IDENTIFICATION

Available, qualifies 3PLs form the pool of alternatives in MADM system. They can be determined in various ways depending on the size of decision-making problem. When the number of 3PLs and basic requirements they should meet are limited, all available 3PLs can be alternatives in MADM model. When the number of 3PLs is high, and they should meet many factors, alternatives can be achieved by initial screening systems of through an MODM model. Attributes and their weights can be determined based on the experts' ideas or historical records.

2.2. RATING MODEL

There are several methods to rate alternatives, and in fuzzy environment, these methods have been widely developed since 1970s (Baas and Kwakernaak 1977, Dubois and Prade 1982, Dubois et al. 1988, Chen and Hwang, 1992).

Among them, methods based on α-cut approach are comprehensive and effective. Current study uses α-cut approach in developing its rating model and follows Baas and Kwakernaak (1977) method in the algorithm of calculations.

Rating algorithm

If MADM model has m alternatives; A_i, $i=1,\dots,m$ and n attributes, y_j, $j=1,\dots,n$,each of them has its own weight: w_j , $j=1,\dots,n$, then x_{ij} is defined as the performance score of alternative A_i with respect to attribute y_j and its weight w_j . Accordingly, for each alternative, a utility function is defined as $U_i = \sum_{j=1}^{n} w_j x_{ij} / \sum_{j=1}^{n} w_j$, which represents how well one alternative satisfies the decision maker's utility. When w_j and x_{ij} are fuzzy, they are defined as:

$$w_j = \{(s_j, \mu_{w_j}(s_j))\}, \quad \forall j$$

and

$$x_{ij} = \left\{(r_{ij}, \mu_{x_{ij}}(r_{ij}))\right\}, \ \forall i, j$$

Then, using α–cut method, U_i is calculated for each x. α–cut results in two points for s_j and two points for r_{ij} (see figure 2). When there are n attributes and n weights, there exist 2^{2n} combination for each α–cut (figure 3). Among these 2^{2n}, maximum and minimum of them creates right part and left part of utility function U_i for each α-cut (figure 4). Browsing αs between 0 and 1, arises utility function, U_i for each alternative (which is a fuzzy set).

Clearly, when each of x_{ij} or w_j is crisp, the procedure would be same as described and calculations will be much easier.

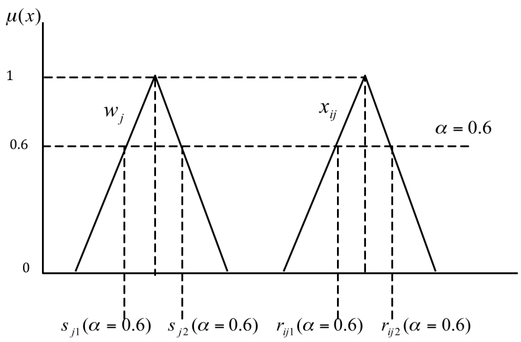

Figure 2: Illustration of α -cut method.

According to above explanations, the rating algorithm can be presented as follows:

Step 1: For alternative 1 to m ($A_1,\ldots,A_m$) verify related x_{ij}s and w_js j=1,…,n).

Step 2: For α= 0 to1 (steps of α depends on membership function and required precision for the problem), calculate U_i s for each α.

Step 3: For each α, determine the maximum and the minimum of U_is.

Step 4: Go to step 2 for next α.

Step 5: Create U_i using gathered U_is in step 3.

Step 6: Go to step 1 for next alternative.

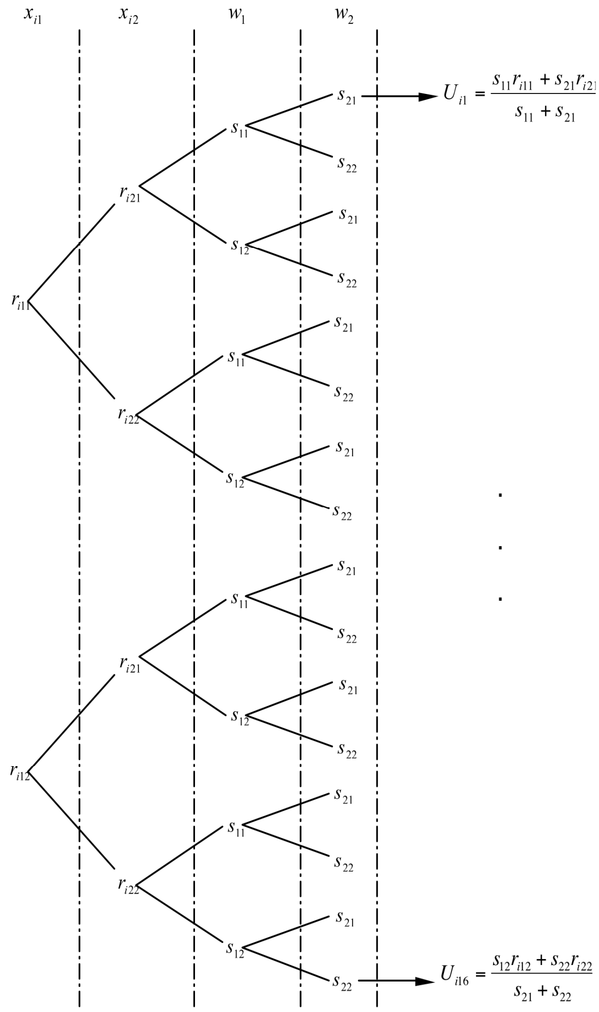

Figure 3: Combination of r_{ij} and s_j at each α -cut in the case of two attributes-two weights.

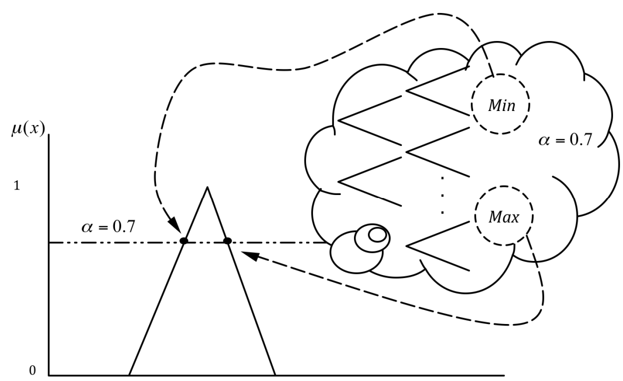

Figure 4: Procedure of creation of the utility function for each alternative.

2.3. RANKING MODEL

After achieving *m* utility functions from rating model, now they should be ranked. Ranking crisp numbers is obvious. However, for ranking fuzzy numbers, some conflicts and complexities happen. Various methods have been developed for ranking fuzzy numbers. Some of them just focus on two fuzzy numbers, while some have the ability to compare multiple fuzzy numbers (Yuan, 1991, Yager 1981, Dubois and Prade 1983). Among these methods, Yuan (1991) after reviewing previous works in this area describes criteria for evaluating fuzzy ranking methods and offers his method, which satisfies all criteria. The discussed criteria that are stated as desired properties for fuzzy ranking methods are "fuzzy preference presentation", "rationality of fuzzy ordering", "distinguishability", and "Robustness".

In current study, Yuan (1991) method will be utilized due to its totality and simplicity as well.

Ranking algorithm

Ranking method of Yuan (1991) is a combination of Nakamura (1986) and Baas and Kwakernaak (1977). However, instead of comparing two fuzzy numbers A_i and A_j, Yuan's method works on the membership function of A_i-A_j to point out the preference of alternative *i* over alternative *j*. Membership function of A_i-A_j is achieved as follows:

$$\mu_{A_i-A_j}(z) = Sup(\mu_{A_i}(x) \wedge \mu_{j}(y))$$
$$x, y, x-y=z$$

Accordingly, the membership function of preference of A_i over A_j defined as

$$\mu_Q(A_i, A_j) = \begin{cases} (S_1+S_2)/S & S>0 \\ 1/2 & S=0 \end{cases}$$

where

$$S_1 = \int_{\{\beta:\rho_{A_i-A_j}(\beta)>0\}} \rho_{A_i-A_j}(\beta)d\beta$$

$$S_2 = \int_{\{\beta:l_{A_i-A_j}(\beta)>0\}} l_{A_i-A_j}(\beta)d\beta$$

$$S_3 = \int_{\{\beta:\rho_{A_i-A_j}(\beta)<0\}} \rho_{A_i-A_j}(\beta)d\beta$$

$$S_4 = \int_{\{\beta:l_{A_i-A_j}(\beta)<0\}} l_{A_i-A_j}(\beta)d\beta$$

$$S = S_1 + S_2 + S_3 + S_4$$

and

$$\rho_{A_i-A_j}(\beta) = \underset{\mu_{A_i-A_j}(z)\geq\beta}{Sup}(z),$$

$$l_{A_i-A_j}(\beta) = \underset{\mu_{A_i-A_j}(z)\geq\beta}{Inf}(z),$$

An illustration of above calculations is shown in figure 5.

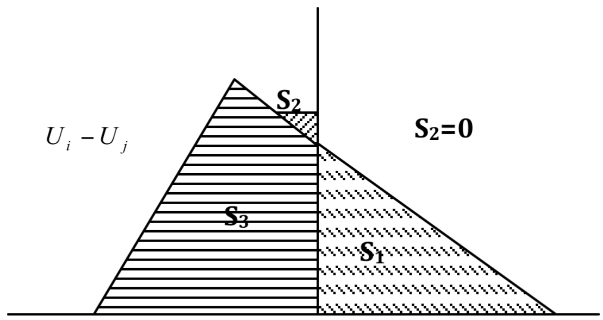

Figure 5: An illustrative example of calculating $\mu_Q(U_i, U_j)$.

After pair-wise comparisons of all alternatives, a $m \times m$ matrix will be resulted which shows all preferences.

Subsequently, further to reciprocity ($\mu_Q(U_i,U_j)=1-\mu_Q(U_i,U_j)$) and transitivity (if $\mu_Q(U_{i,}U_j)\geq 1/2$ and $\mu_Q(U_{i,}U_k)\geq 1/2$ then $\mu_Q(U_{i,}U_k)\geq 1/2$), the final ranking of *m* alternatives will be derived easily. Hence the ranking model could be fulfilled according to the following steps:

***Step 1*:** For *i* = 1,…,*m* and *j* = 1,…,*m* calculate $\mu_Q(U_i,U_j)$

***Step 2*:** Establish the comparison matrix, while its (*i,j*) array gains $\mu_Q(U_i,U_j)$ value.

***Step 3*:** Each alternative *i*, which its $\mu_Q(U_{i,}U_j)\geq 1/2\ \forall_j=1,...,m$, will be first in ranking. Remaining alternatives will be ranked similarly.

2.4. NUMERICAL EXAMPLE

Now, after explanation of the fuzzy MADM Procedure in 3PL selection, a numerical example is presented (data are used from Wang *et al.,* 2000). The problem consists of 10 alternatives and 4 attributes. The first three attributes are to be minimized and the last one should be maximized. Furthermore, all attributes are assumed to be crisp, while, their weights are fuzzy. Weights for attributes are defined as follows:

Attribute 1: very important

$$(\mu_{\tilde{w}_1}(w_1) = e^{-1262.67(w_1-1.0)^2}, 0 \le w_1 \le 1)$$

Attribute 2: important

$$(\mu_{\tilde{w}_2}(w_2) = e^{-1262.67(w_2-0.8)^2}, 0 \le w_2 \le 1)$$

Attribute 3: medium important

$$(\mu_{\tilde{w}_3}(w_3) = e^{-1262.67(w_3-0.6)^2}, 0 \le w_3 \le 1)$$

Attribute 4: very important

$$(\mu_{\tilde{w}_4}(w_4) = [e^{-1262.67(w_4-0.8)^2}]^2, 0 \le w_4 \le 1)$$

Attributes values for alternatives and normalization of them are show in Table 1 and Table 2 respectively.

Now using Baas and Kwakernaak (1977) method for rating, utility function for each alternative will be achieved.

As an example, for alternative 1 and $\alpha = 0.5$, $U_1 s$ are 0.87634, 0.87655, 0.87459, 0.87475, 0.87691, 0.8771, 0.87511, 0.87528, 0.87683, 0.87701, 0.87502, 0.87519, 0.87738, 0.87758, 0.87556, 0.87573, where maximum and minimum of them are 0.87758 and 0.87459 irrespectively. Wang *et al.* (2000) used rating algorithm of Liou *et al.* (1992), However, Baas and Kwakernaak method, despite its simplicity, is more effective while all parameters of the problems are fuzzy. After achieving utility function for each alternative, they are entered into ranking model. This part of the solution is same as Wang *et al.* (2000), which used Yuan (1991) method for ranking. Table 3, shows the resulted ranking of current Solution and compares it with result of Wang *et al.* (2000) with the same set of data.

Table 1: Values of attributes for alternatives.

	Attributes			
Alternatives	A1	A2	A3	A4
1	581 818	54.49	3	5 500
2	595 454	49.73	3	4 500
3	586 060	51.24	3	5 000
4	522 727	45.71	3	5 800
5	561 818	52.66	3	5 200
6	543 030	74.46	4	5 600
7	522 727	45.42	4	5 800
8	486 970	62.62	4	5 600
9	509 394	65.87	4	6 400
10	513 333	70.67	4	6 000

Table 2: Normalized values of attributes for alternatives

	j			
i	**1**	**2**	**3**	**4**
1	0.854	0.839	1.0	0.859
2	0.835	0.919	1.0	0.703
3	0.848	0.892	1.0	0.781
4	0.981	1.0	1.0	0.906
5	0.885	0.868	1.0	0.812
6	0.915	0.614	0.75	0.875
7	0.951	0.606	0.75	0.906
8	1.0	0.730	0.75	0.875
9	0.976	0.694	0.75	1.0
10	0.968	0.647	0.75	0.938

Table 3: Comparison of ranking alternatives in current solution and Wang *et al.* (2000) results.

Alternatives	1	2	3	4	5	6	7	8	9	10
Rank in Current Solution	3	7	4	1	2	10	4	6	5	8
Rank in Wang et al. (2000)	4	5	3	1	2	10	9	6	7	8

As it is clear, there is no major difference between two methods. However current approach is more effective in fully fuzzy problems. This fact will be challenged in next section, while a more complex case study will be argued.

3. CASE STUDY

After detailed description of the architecture of the MADM approach in 3PL problems, in this section, a complex problem is examined. Despite the simple numerical example in last section, which was based on what Wang *et al.* (2000) had represented, the current real-world problem has both fuzzy and crisp attributes with fuzzy weights. Furthermore, a wider range of realistic attributes is considered. Structure and elements of the problem would be as explained in following subsections.

3.1. PROBLEM DESCRIPTION

The problem at a glance is a 3PL selection problem in the framework of a MADM model. There are ten alternatives, which are to be evaluated under six different attributes. The attributes are as follows.

a) Average cost of providing logistics services.
b) Average distance from warehouse locations.
c) Average delivery time.
d) Variation in service level.
e) Access to production resources.
f) Knowledge of logistics management.

Attributes (a) to (d) are to be minimized, and attributes (e) and (f) should be maximized. Besides, as it is clear, attributes (d), (e) and (f) have fuzzy nature, while three others are assumed non-fuzzy. Table 4 shows the values of alternatives under attributes and relating significance of attributes.

Table 4: Attributes weights and their values for all alternatives.

Alternatives	Attributes					
	(a) *Cost ($1000)*	*(b)* *Distance (mile)*	*(c)* *Delivery time (week)*	*(d)* *Variation in service level*	*(e)* *Production resources*	*(f)* *Knowledge of logistics*
1	30	52	3	High	Low	Low
2	40	60	3	Very high	Medium	Low
3	50	68	3	High	High	Medium
4	45	55	3	Very High	Medium	Medium
5	40	74	4	High	Low	Low
6	55	70	4	Medium	Medium	Medium
7	50	80	4	Medium	Medium	Medium
8	60	77	4	Low	High	High
9	55	92	5	Low	Low	High
10	70	88	5	Very low	Medium	High
Weight	Important	Rather Important	Ordinary	Important	Rather Important	Very Important

Fuzzy values of weights and alternatives under attributes (d), (e), and (f) which have been stated in the form of linguistic variables, could mapped as fuzzy sets. Figures 6 to 9 illustrate the appropriate fuzzy sets and membership functions of the above linguistic variables. Membership functions are assigned triangular shapes, which reflect the behaviour of fuzzy sets. The shape of the membership function can vary depending on the attribute's nature.

As it is obvious, above fuzzy variables (attributes and their weights) are normal (between 0 and 1). Subsequently, other three variable of the problem, which are attributes (a), (b), and (c) can be normalized as shown it table 5.

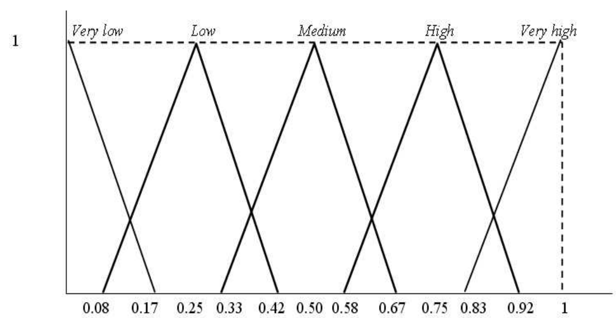

Figure 6: Illustration for fuzzy set of attribute (d); "Variation in service level".

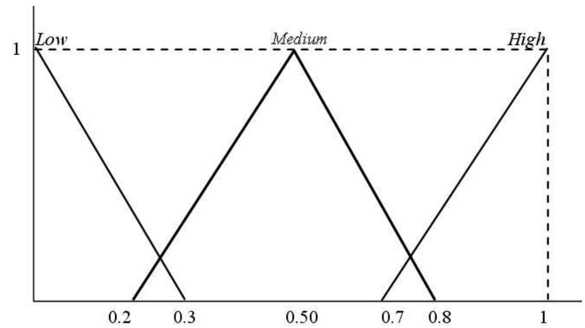

Figure 7: Illustration for fuzzy set of attribute (e); "Production

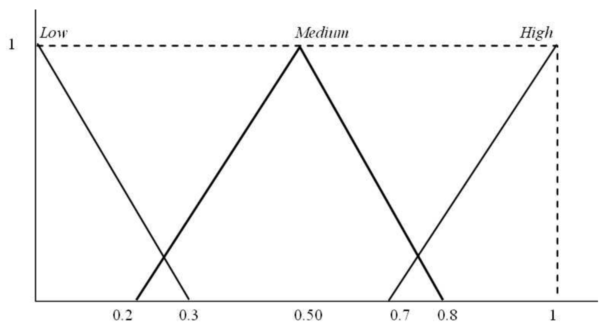

Figure 8: Illustration for fuzzy set of attribute (f) "Knowledge of logistics"

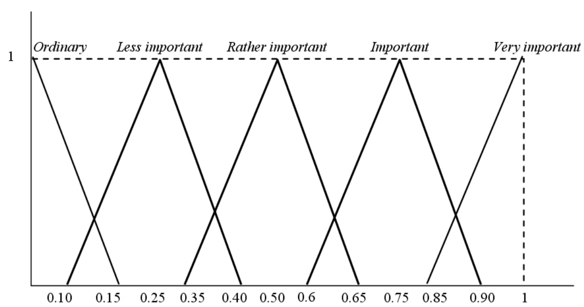

Figure 9: Fuzzy set of attributes weights.

Table 5: Normalised values of non-fuzzy attributes.

Alternative	Attributes		
	Cost	Distance	Delivery time
1	1	1	1
2	0.75	0.87	1
3	0.60	0.76	1
4	0.67	0/95	1
5	0.75	0.70	0.75
6	0.55	0.74	0.75
7	0.60	0.65	0.75
8	0.50	0.68	0.75
9	0.55	0.57	0.6
10	0.43	0.59	0.6

Now, according to attributes and alternative as input data, the stepwise process of solving the problem, which was explained in previous section, will be followed.

3.2. RATING ALTERNATIVES

As the algorithm of rating model described in 2.2, the utility functions of alternatives are resulted as Figure 10. All programmes and calculations of this process are available with author for interested readers.

3.3. RANKING UTILITY FUNCTIONS

In accordance with the illustrated flow–chart in Figure 1 for solving 3PL selection problems via MADM, now after achieving utility functions of alternatives, they should be ranked. Ranking algorithm is exactly what was interpreted in section 2.3. Accordingly, the resulted matrix of comparisons is as shows in Table 6.

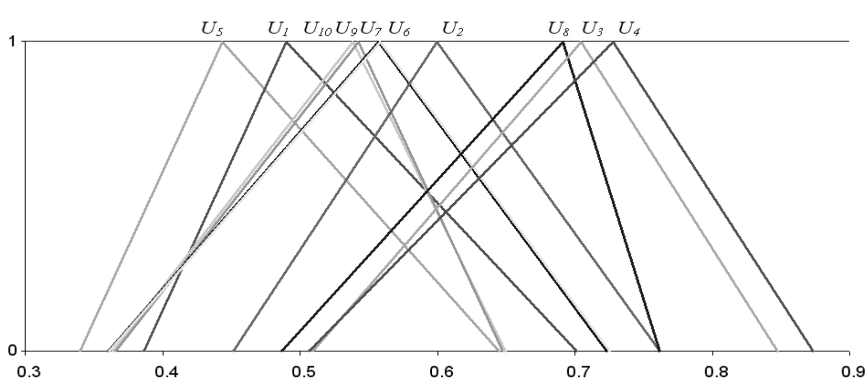

Figure 10: Utility functions of 3PLs resulted by rating model.

Table 6: Comparison matrix.

i	*j*									
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	0.5	0.25098	0.10478	.092166	.65293	0.40638	0.41261	0.14783	0.48318	0.49508
2	0.75716	0.5	0.25882	0.22439	0.86041	0.66337	0.67146	0.34359	0.76842	0.77886
3	0.90027	0.74948	0.5	0.44869	0.9536	0.84948	0.8553	0.6225	0.92579	0.92951
4	0.91254	0.78336	0.56144	0.5	0.959	0.86923	0.8743	0.67635	0.93647	0.93941
5	0.35629	0.1456	0.04956	0.04396	0.5	0.28045	0.28508	0.07604	0.33446	0.34421
6	0.60344	0.34608	0.15694	0.13673	0.72811	0.5	0.5121	0.2153	0.59227	0.60389
7	0.59729	0.33798	0.15105	0.13158	0.72357	0.49828	05	0.20826	0.5853	0.59703
8	0.85831	0.66564	0.38724	0.33294	0.92806	0.79231	0.79929	0.5	0.88322	0.88899
9	0.52673	0.23956	0.07842	.06739	0.67462	0.41778	0.42484	0.12229	0.5	0.5183
10	0.51493	0.22906	.07465	0.06441	0.66503	0.4062	0.41316	0.11646	0.49202	0.5

Next, it could be easily gained from the comparisons that 3PL 4 has most preference of all other alternatives. After 3PL 4, 3PL 3 and 8 are very close to it and have next priorities respectively. According to comparisons of Table 6, and as it is also clear from Figure 9, preference of these three 3PLs over others is reasonable. After these three, ranking of the rest of 3PLs is as follows: 2,6,7,9,10,1,5.

4. CONCLUSION

In this paper, a comprehensive model for 3PL selection problems has been developed in fuzzy environment of decision–making. A step–by–step procedure for fuzzy MADM system was explained and a numerical example of previous works was solved. Next, a case study was introduced and the parameters and variables of the problem were determined. Accordingly, using the proposed procedure, the problem was solved and results were analysed.

Modelling and solving 3PL selection problems in a fully fuzzy nature using MADM, as well as introducing comprehensive attributes were two main contributions of this study. Developing methods in achieving input alternatives to MADM problem, using expert system methods in 3PL selection problem, and combination of MADM and MODM approaches in solving these types of problem, could be considered for future works.

BIBLIOGRAPHY

[1] Baas, S.M.; Kwakernaak, H., 1977. “Rating and ranking of multiple aspect alternative using fuzzy sets”, Automatica 13, pp. 47-58.

[2] Browne, M., Allen, J., Woodburn, A., 2007. Developments in Western European logistics strategies. In Water, D. (Ed.) global Logistics: New Directions in Supply Chain Management, Kogan Page, London.

[3] Chan, H.K., Wang, W.Y.C., Luong, L.H.S., Chan, F.T.S., 2009. Fexibility and adaptability in supply chains: a lesson learnt from a practitioner. Supply Chain Management: An International Journal, 14(6), 407-410.

[4] Chen , S.J.; Hwang , C.L.; HWANG, F.P., 1992. “Fuzzy Multiple Attribute Decision Making: Methods and Application”, Berlin: Springer.

[5] Christopher, M., 2000. Supply chain migration from lean and functional to agile and customised. Supply Chain Management: An International Journal, 5(4), 206-213.

[6] Coyle, J.J., Bardi, E.J., Langley, C.J., 2003. The Management of Business Logistics—A Supply Chain Perspective. South- Western Publishing, Mason.

[7] Dubois, D.; Prade, H., 1982. “The use of fuzzy numbers in decision analysis”, Fuzzy information and decision processes, North-Holland, pp. 309-321.

[8] Dubois, D.; Prade, H., 1983. “Ranking of fuzzy numbers in the setting of possibility theory”, Information Sciences, 30, pp. 183-224.

[9] Dubois, D.; Prade, H.; Testemale, C., 1988. “Weighted fuzzy pattern matching”, Fuzzy sets and systems, 26, pp. 225-242.

[10] Evangelista, P., Sweeney, E., 2006. Technology usage in the supply chain: The case of small 3PLs. The International Journal of Logistics Management, 17(1), 55–74.

[11] House, R.G., Stank, T.P., 2001. Insights from a logistics partnership. Supply Chain Management: An International Journal, 6 (1), 16–20.
[12] Hwang, C.L.; Yoon, K., 1981. "Multiple attribute decision making methods and applications, A stateof-the-art survey", Springer, New York.
[13] Liou, T. S., Jiun,M. and Wang, J., 1992, Fuzzy weighted average: an improved algorithm. Fuzzy Sets and Systems, 49, 307-315.
[14] Marasco, A., 2008. Third-party logistics: A literature review, International Journal of Production Economics, 113(1), 127-147.
[15] Modarres, M., Saadinejad, M., 2001. "Ranking fuzzy numbers by preference ratio", Fuzzy Sets and Systems 118, pp. 429-436.
[16] Nakamura, K., "Preference relations on a set of fuzzy utilities as a basis for decision making", Fuzzy Sets and Systems, Vol. 20, pp. 147-162.
[17] Saura, I.G., Francés, D.S., Contrí, G.B., Blasco, M.F., 2008. Logistics service quality: a new way to loyalty, Industrial Management & Data Systems,108(5), 650-668.
[18] Spencer, M.S., Rogers, D.S., Daugherty, P.J., 1994. JIT Systems and External Logistics Suppliers. International Journal of Operations & Production Management. 14(6), 60-74.
[19] Trentin, A., 2011. Third-party logistics providers offering form postponement services: value propositions and organisational approaches. International Journal of Production Research, 49(6), 1685-1712.
[20] Vaidyanathan, G., 2005. A framework for evaluating third-party logistics. Communications of the ACM, 48(1), 89–94.
[21] Varila, M., Seppänen, M., Suomala, P., 2007. Detailed cost modelling: a case study in warehouse logistics. International Journal of Physical Distribution & Logistics Management, 37(3), 184-200.
[22] Voss, H., 2003. International logistics outsourcing—Competitive advantages for 3PL-providers through intercultural compe- tence. In: Juga, J. (Ed.), Proceedings of the 15th Annual Conference for Nordic Researchers in Logistics: Striving for Leading Edge Logistics, 12–13 June, Faculty of Economics and Business Administration, University of Oulu, Oulu, Finland, 447–463.
[23] Wang, T.; Shaw, C.; Chen, Y., 2000. "Machine selection in flexible manufacturing cell: a fuzzy attribute decision making approach", Int. J. Prod. Res., Vol. 38, No. 9, pp. 2079-2097.
[24] Yager, R.R., 1981, "A procedure for ordering fuzzy subsets of the unit interval" Information Science, 24, pp. 143-161.
[25] Yuan, Y., 1991. "Criteria for evaluating fuzzy ranking methods", Fuzzy Sets and Systems, 44, pp. 139-157.
[26] Zhu, B., Wang, Z., Yang, h., Mo, R., and Zhao, Y., 2008. Applying fuzzy multiple attributes decision making for product configuration. Journal of Intelligent Manufacturing, 19(5), 591-598.
[27] Zimmermann, H.J., 1996. "Fuzzy Sets Theory and its Applications", third edition, Boston, Kluwer Academic