INTEGRATED SUPPLIER SELECTION MODEL USING ANP, TAGUCHI LOSS FUNCTION AND PROMETHEE METHODS

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Abstract
*Supplier evaluation and selection process is one of the most important decision problem for companies. **S**upplier selection is a Multi-criteria decision making (MCDM) process, since the problem involves both tangible, intangible and also conflicting criteria. In this study a group of main criteria; "quality", "delivery", "price", "environmental health", "financial status", "managerial capabilities" and "working conditions" are searched for their interrelations and importance degrees. Analytic network process (ANP) is used for calculations of the weights of the criteria and these weights have been transferred to quality loss via Taguchi loss functions. A case study in automotive industry is presented and finally a comparison with PROMETHEE method is discussed. This study presents a delicate and precise solution to a complex selection problem by comparing traditional and non-traditional methods.*

Keywords: *ANP, MCDM, Supplier selection, Taguchi loss function, PROMETHEE*

1. Introduction

In recent years, evaluating and selecting the best supplier has become a strategic decision for companies. With the increased level of outsourcing, much attention needs to be paid to the supplier selection and evaluation (Sharma and Balan 2012). Giving more importance in supplier selection process allows the purchasers to have long term relationship with their suppliers and hence have a competitive advantage in industrial market. The overall objective of the supplier evaluation process is to reduce risk and maximize overall value to the purchaser (Zeydan et al. 2011).

Supplier selection problem may involve both tangible and intangible criteria which are conflicting or affecting each other. Therefore supplier selection can be considered as a multi-criteria decision making (MCDM) problem that the selection process mainly involves evaluating a number of suppliers according to a set of common criteria for selecting suppliers to meet business needs (Liao and Kao 2010).

This paper is aimed to select the best supplier by means of multi-criteria decision making techniques. The proposed model tries to select the best supplier by integrating analytic network process with Taguchi loss function and PROMETHEE methods. In the last section of this study, for application, two integrated methods are developed for supplier selection in a tire manufacturing company based on "quality", "delivery", "price", "environmental health", "financial status", "managerial capabilities" and "working conditions" criteria. While modeling these criteria, weights have been calculated by using ANP. These weights are combined with scores of four suppliers by using Taguchi loss function and PROMETHEE methods for selecting the best supplier.

2. Literature review

In literature a large number of alternative methods have been used for evaluating and selecting the suppliers since the initial study of Dickson in 1966 (Dickson 1966). Most of these models make decision making on supplier selection based on a set of supplier performance criteria (Pi and Low 2006). Selected models differ from each other by having one or multi- objective or having different criteria.

The early models of supplier selection process, the problem has been considered as a single objective problem. Single objective weighted linear model was used by Timmerman (1986). Cost based approaches such as total cost of ownership method were some of the one objective methods in literature used by Ellram (1995), Degraeve et al. (2000) and Bhutta and Huq (2002).

In order to solve conflicting selection problems, mathematical models were developed in 1980's. Talluri and Narasimhan (2003), Ng (2008), Guneri et al. (2009) proposed a solution to this problem by means of linear programming. Integer linear programming (Chaundry et al. 1993), (Rosenthal et al. 1995); integer non-linear programming (Ghodsypour and O'Brien 2001); multi-objective programming (Weber and Ellram 1993), (Gao and Tang 2003), (Kannan 2013); goal programming (Karpak et al. 2011), (Chang et al. 2013); data envelopment analysis (Kuo and Lin 2012), (Partovi 2013) are some mathematical programming models which are used for supplier selection.

In recent years MCDM techniques are widely used for supplier selection. Since the evaluation always involves several and generally conflicting performance criteria, MCDM techniques help decision makers to manage the problem. Chai at al.(2013) classified the basic MCDM techniques into four categories: (1) multi-attribute utility methods such as Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP); (2) outranking methods such as Elimination and Choice Expressing Reality (ELECTRE) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE); (3) compromise methods such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Multi- Criteria Optimization and Compromise Solution (VIKOR); and (4) other MCDM techniques such as Simple Multi-Attribute Rating Technique (SMART) and Decision-Making Trial and Evaluation Laboratory (DEMATEL).

AHP and ANP have been used in different supplier selection problems. Kokangul and Susuz (2009), Rouyendegh and Erkan (2012), Labib (2011) used AHP method in their studies. Bayazıt (2006), Jharkharia and Shankar (2007), Gencer and Gurpinar (2007), Lin (2012), Pang and Bai (2013), Govindan et al. (2013) used ANP method to solve supplier selection problem. Shyur and Shih (2005) used ANP and TOPSIS integrated method for supplier selection. Lin (2012) combined FANP (Fuzzy Analytic Network Process) with multi-objective linear programming method.

The study of Dulmin and Mininno (2003) investigated the contribution of PROMETHEE and GAIA (Geometrical Analysis for Interactive Aid) method for supplier selection problems. Radfar and Salahi (2014), proposed a hybrid model combining fuzzy DEA and PROMETHEE methods together in order to solve supplier selection problem in a manufacturing company. ELECTRE method was first proposed as an outranking concept by Royin 1974 (De Boer et al. 1998). Sevkli (2010) applied fuzzy ELECTRE method to supplier selection.

Zeydan et al. (2011) used a combined methodology including fuzzy AHP, fuzzy TOPSIS and DEA (Data Envelopment Analysis) for supplier selection and performance evaluation. Kasirian and Yusuff (2012) applied hybrid modified TOPSIS with a PGP (Preemptive Goal Programming) for the supplier selection with interdependent criteria. Li et al. (2012) combined FAHP (Fuzzy Analytic Hierarchy Process) with TOPSIS in supply chain management.

Sanayei et al. (2010) proposed their model for supplier selection in a firm that manufacturing automobile parts by using fuzzy VIKOR under fuzzy environment. Shemshadi at al. (2011) used a fuzzy VIKOR method based on entropy measure for objective weighting. Chang et al. (2011) made use of fuzzy DEMATEL method for developing supplier selection criteria. Chou and Chang (2008) used a strategy-aligned fuzzy SMART approach for building a decision support system for supplier selection problem.

Pi and Low (2006), evaluated supplier's attributes by using Taguchi loss function and transferred these losses into a variable for decision making by AHP method. Liao and Kao (2010) integrated Taguchi loss function, AHP and Multi-Choice Goal Programming (MCGP) model for solving a supplier selection problem with five criteria and five suppliers. Liao (2010) used Delphi technique to obtain the criteria, then transferred them into Taguchi loss function and combined with AHP based weights for selecting the best supplier in a food manufacturing factory. Ordoobadi (2010) used Taguchi loss function to measure the performance of each of three suppliers of a manufacturing company. AHP method was used to determine the relative importance of the criteria and the supplier with the minimum loss is selected. Sharma and Balan (2012) integrated Taguchi loss function with TOPSIS and multi-criteria goal programming to indentify the best performing supplier in a manufacturing company in automotive industry.

3. The proposed model

In this study, the methodology for selecting the best supplier has two steps: (1) the criteria for supplier selection process are determined. Relative weight of each criteria are determined by using ANP method, (2) suppliers are evaluated according to their performance, Taguchi loss function and PROMETHEE methods are used comparatively for selecting the best supplier.

3.1. Analytic network process

ANP is a special form of AHP and it can be used to solve more complex decision problems. As an extension of AHP, ANP takes into consideration the interdependence of attributes of criteria and defines the selection problem as a network. This network can include both tangible and intangible variables. The weights of each criterion are derived by means of pair wise comparisons in ANP method. The fundamental comparison scale for ANP which is proposed by Saaty (2009) is shown in table (1).

Table 1. The scale for ANP

Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

The ANP methodology can be explained step by step approach as following:

1. In the first step, the problem is formulated. In this step, the aim, main criteria, sub criteria and alternatives (suppliers) should be identified clearly.
2. Interdependencies of criteria are formulated and paired comparisons between clusters and elements are performed.
3. The consistency of pair wise comparison matrices is determined. If the consistency ratio (CR) is equal or smaller than 0.1 value, the comparisons are consistent.
4. The next and final step is to contract the super matrix. The super matrix is a partial matrix including pair wise comparisons. Weighted limit super matrix gives us the weights (relative importance) of each criterion.

3.2. Taguchi loss function

Dr. Genichi Taguchi has developed a method called Taguchi method to increase process and product quality after The Word War II. Compared to conventional methods, Taguchi method which helps saving time and money has been used for a long time for quality control since that time period. In recent years this method is also used for evaluating the performance of suppliers.

Taguchi loss function can be expressed as a function of deviation from ideal or target value of a given design parameter (Roy 1990). Taguchi's loss function is classified into three types of functions: "the smaller the better", "the larger the better" and "a specific target value is the best" (Dehnad 1985).

The proper function depends on the magnitude of variation, such variation being allowed in both directions from the target value (Pi and Low 2006). In the context of the specific target value is the better quality characteristics, the target value will be at the center and the two sides give the upper and lower specification limits (Sharma and Balan 2012).

Nominal-is-best Taguchi loss function can be formulated as follows (Roy 1990):

$L(y) = k(y - m)^2$ (1)

where

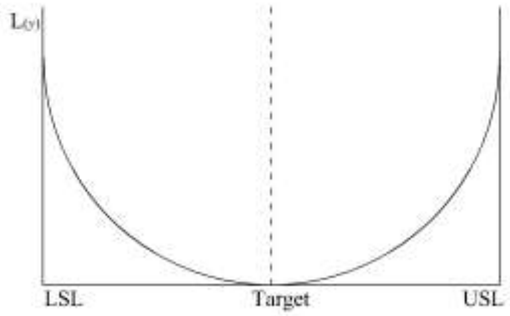
y: The quality characteristics, such as performance

m: The target value for the quality characteristic

k:A constant which is dependent upon the structure of a manufacturing process or organization

Here, the term (y –m) represents the deviation from the target value m. This target can be at the center within two sided (lower and upper) specification limits (Fig.1). LSL presents Lower Specification Limits and USL presents Upper Specification Limits.

Fig. 1. Nominal-is-better loss function



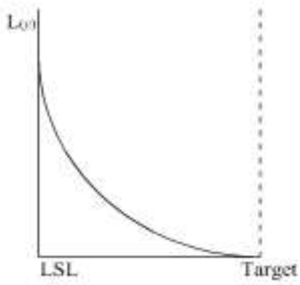
The other two loss functions include the one-sided minimum specification limit called smaller-is-better (Fig.2) and one-sided maximum specification limit called larger-is-better (Fig.3) which are formulated in equation (2) and equation (3) respectively.

$L(y) = k.\ (y)^2$ (2)

$L(y) = k / y^2$ (3)

Fig. 2. Smaller-is-better loss function

Fig. 3. Larger-is-better loss function



3.3. PROMETHEE Method

Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) is a multi-criteria decision making method developed by Brans et al. (1986). PROMETHEE is a simple outranking method to solve the decision problems with finite number of alternatives. The implementation of PROMETHEE method requires the weights of the criteria and the decision function to evaluate the alternatives in terms of each criterion. In this study the weights of the criteria are determined by using ANP method. And these weights are combined with the preference function of PROMETHEE. The preference function (P_j) translates the difference between the evaluations obtained by two alternatives in terms of a particular criterion, into a preference degree (Macharis et al. 2004):

$$P_j(a,b) = G_j\left[f_j(a) - f_j(b)\right] \quad (4)$$

$0 \leq P_j(a,b) \leq 1$

where

P_j : Preference function

$f_j(.)$: Criterion

G_j: No decreasing function of observed deviation between $f_j(a)$and$f_j(b)$.

PROMETHEE introduces more functions to describe decision making preferences for each criterion with a clearer interpretation of the parameters (Dulmin and Mininno 2003). Brans and Vincke (1985) proposed six basic types of function: (1) usual criterion, (2) U-shape criterion, (3) V-shape criterion, (4) level criterion, (5) V-shape with indifference criterion and (6) Gaussian criterion. PROMETHEE I provides partial ranking where PROMETHEE II provides a full ranking of all actions.

4. A case application

This study establishes and demonstrates the application of the proposed methods for supplier selection in a tire manufacturing company that produces tire for cars, motorcycles, trucks and buses. The company is one of the leading tire companies in automotive industry in Turkey. The company outsources "Automation System" activities from four different suppliers. It has been aimed to evaluate suppliers and choose the one who better meets the needs and expectations of the company. Supplier selection process starts with the determination of the criteria by a team made up of experts from purchasing, finance, engineering, quality control and work safety departments."Quality", "On-time delivery", "Price" and "Service" are the most common criteria in a supplier selection problem. In this study, the expert team determined seven main criteria and thirty one sub criteria which are already used to evaluate the suppliers of the company (In table (2) main criteria and sub criteria are given).

Table 2. Main and sub criteria

Criteria	Explanation
Quality	Quality of service and/or product
Q1	Percentage of defective products (real value)
Q2	Continuous improvement
Q3	Quality control system
Q4	Quality certificate
Delivery	On time and appropriate delivery
D1	Compliance with the packaging requirements
D2	Accurate billing
D3	Flexibility to deadline changes
D4	Delay in delivery (real value)
D5	Delivery according to the order quantity
D6	On time order bid, confirmation and billing
Price	Price level
P1	Price level (real price)
P2	Effectiveness in reducing costs

P3	Payment term
Env. Health	Environmental health and work safety
E1	Having knowledge about environmental health and work safety
E2	Providing safety training to employees
E3	Taking account of the environmental impact of the production process
E4	Taking safety precautions
E5	Having clean and tidy working environment
Fin. Status	Financial status
F1	Financial transparency
F2	Having detailed financial statements
F3	Adequate financial structure
Man. Cap.	Managerial capabilities
M1	Providing services to other firms
M2	Having modern communication tools
M3	Having a good organizational structure
M4	Having now how about the company
M5	The availability of responsible staff
M6	Educated and experienced management team
Work. Con.	Working conditions
W1	Having a clear policy on discipline and discrimination
W2	Providing the employee the necessary training
W3	Compliance with legislation on social benefits and overtime
W4	Having handbook of management

Automation system activities involve mainly the software, montage and maintenance of machines which are used in computer aided manufacturing. The norm decision matrix shows us the performance scores of supplier's for each criterion (Table 7). The norm matrix is determined by purchasing experts and is based on "0-5" scale. The following analyses by ANP, Taguchi and PROMETHEE methods are based on the norm matrix.

4.1. Application of ANP Method

In order to apply ANP method, the purchasing department of the company developed a pair wise comparison matrix that shows the relative importance of each criterion by considering the company priorities (Table 3). The matrices indicating the contribution of sub criteria to the main criteria and interdependence of criteria are also prepared by purchasing department experts (Table 4 and 5).The pair wise comparisons in the model are based on "0-9" scale which is proposed by Saaty (2009).

Table 3. Main criteria pair wise comparison matrix

	Quality	Delivery	Price	Env. Health	Fin. Status	Man. Cap.	Work. Con.
Quality	1	2	2	3	5	7	7
Delivery		1	1	2	4	6	6
Price			1	2	4	6	6
Env. Health				1	3	5	5
Fin. Status					1	3	3
Man. Cap.						1	1
Work. Con.							1

Table 4. Contribution of sub criteria to the main criteria

Quality	Q_1	Q_2	Q_3	Q_4
Q_1	1	3	5	7
Q_2		1	3	5
Q_3			1	3
Q_4				1

Delivery	D_1	D_2	D_3	D_4	D_5	D_6
D_1	1	3	1/4	1/6	1/2	2
D_2		1	1/6	1/8	1/4	1/2
D_3			1	1/3	3	5
D_4				1	5	7
D_5					1	3
D_6						1
Price	P_1	P_2	P_3			
P_1	1	5	6			
P_2		1	2			
P_3			1			
Env. Health	E_1	E_2	E_3	E_4	E_5	
E_1	1	1	1/5	1/7	1/3	
E_2		1	1/5	1/7	1/3	
E_3			1	1/3	3	
E_4				1	5	
E_5					1	
Fin. Status	F_1	F_2	F_3			
F_1	1	1/2	1/6			
F_2		1	1/5			
F_3			1			
Man. Cap.	M_1	M_2	M_3	M_4	M_5	M_6
M_1	1	1/2	1/4	1/7	1/5	1/3
M_2		1	1/3	1/6	1/4	1/2
M_3			1	1/4	1/2	2
M_4				1	3	5
M_5					1	3
M_6						1
Work. Con.	W_1	W_2	W_3	W_4		
W_1	1	1/3	3	1/5		
W_2		1	5	1/3		
W_3			1	1/7		
W_4				1		

Table 5. Interdependencies

Quality	Price	Delivery	Fin. Status	Env. Health	Man. Cap.	Work. Con.
Price	1	1	3	1	2	4
Delivery		1	1	1	1	1
Fin. Status			1	1	1/2	2
Env. Health				1	1	1
Man. Cap.					1	3
Work. Con.						1
Delivery	**Quality**	**Price**	**Fin. Status**	**Env. Health**	**Man. Cap.**	**Work. Con.**
Quality	1	1	1	1	1	1
Price		1	3	1	2	4
Fin. Status			1	1	1/2	2
Env. Health				1	1	1
Man. Cap.					1	3
Work. Con.						1
Price	**Quality**	**Delivery**	**Fin. Status**	**Env. Health**	**Man. Cap.**	**Work. Con.**
Quality	1	2	1	3	4	5
Delivery		1	1	2	3	4
Fin. Status			1	1	1	1
Env. Health				1	2	3
Man. Cap.					1	1
Work. Con.						1

Pair wise comparison matrices and interdependency matrices are combined and analyzed for ANP solution with the help of "Super Decision 2.2.6" software. The solution gives us the weight of each criterion. These weights indicate the importance degree of criteria with respect to each other and they are used for further analysis with Taguchi and PROMETHEE to select the best supplier.

Table 6. Weights of the main criteria

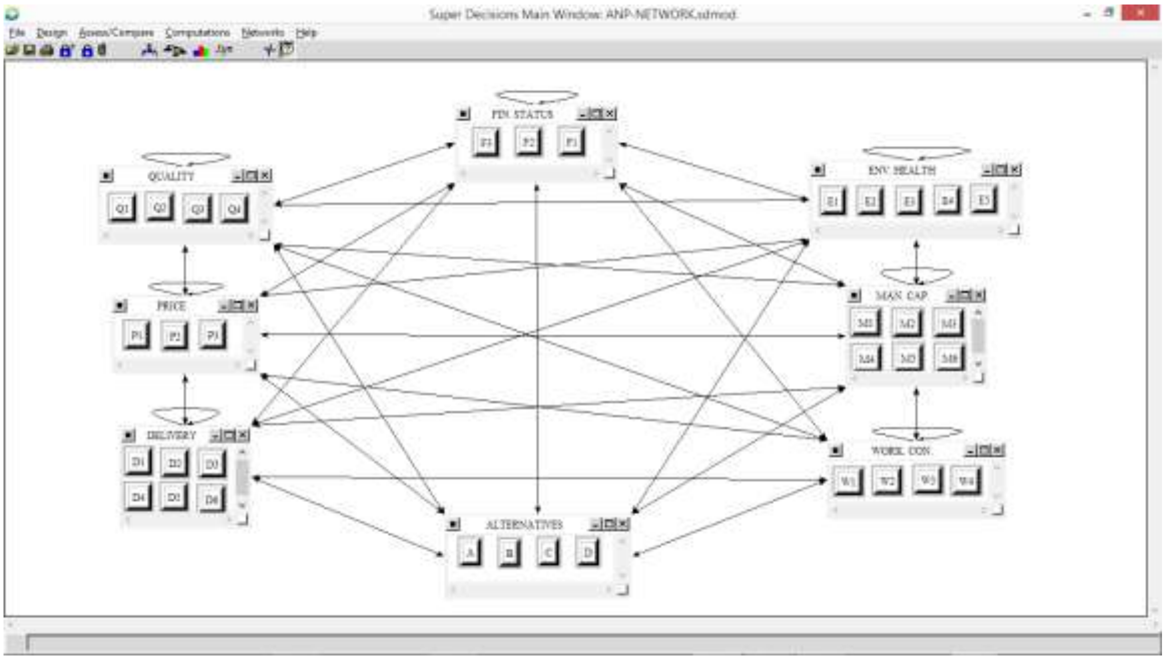
Criteria	Weights	Criteria	Weights
Quality	0,32373	E_3	0,18992
Q_1	0,33165	E_4	0,24208
Q_2	0,25316	E_5	0,20343
Q_3	0,21566	Fin. Status	0,06523
Q_4	0,19953	F_1	0,30776
Delivery	0,20690	F_2	0,31551
D_1	0,14901	F_3	0,37673
D_2	0,13993	Man. Cap.	0,03165
D_3	0,17991	M_1	0,15945
D_4	0,22958	M_2	0,15756
D_5	0,15841	M_3	0,16013
D_6	0,14317	M_4	0,18852
Price	0,20690	M_5	0,16735
P_1	0,40988	M_6	0,16699
P_2	0,20189	Work. Con.	0,03165
P_3	0,28823	W_1	0,24128
Env. Health	0,13395	W_2	0,25081
E_1	0,18229	W_3	0,23718
E_2	0,18229	W_4	0,27073

The judgments used in pair wise comparisons should be consistent. The ANP method measures the consistency of judgments by means of consistency ratio (CR). If the CR is larger than 0,1 the judgments must be revised (Saaty and Vargas 2000). The main criteria comparison matrix is consistent with CR= 0,02147 which is smaller than 0,1 value. All pair wise comparison matrices used in the model are checked that they have CR value smaller than 0,1.

Fig. (4) shows the comparison matrix and the weights of the main criteria. The suppliers are referred to as suppliers A, B, C and D. The network of ANP solution can be seen at fig.(5).

Fig. 4. Main criteria comparison matrix

Fig. 5. The network of ANP model



The measurable criteria (delay in delivery, price level and defective product ratio) are "smaller-is-better", while the other criteria are "larger-is-better". In the standard norm matrix, the rates of these criteria are given according to meet the expectations of the buyer company. The highest rate "5" indicates zero delay, the best price and zero defects. The norm matrix having the rates of four suppliers for each criterion is shown in table (7). The suppliers are referred as A, B, C and D.

Table 7. The norm matrix

	Work. Con.					Quality				
	W_1	W_2	W_3	W_4		Q_1	Q_2	Q_3	Q_4	
A	4	4,3	4	4		4	4	4	4	
B	3	3,3	4	3		4	4	5	4	
C	4	3,6	4	4		4	4	4	4	
D	4	3,6	4	4		4	4	4	4	
	Fin. Status				Env. Health					
	F_1	F_2	F_3		E_1	E_2	E_3	E_4	E_5	
A	4	4	4		4	3	3	4	4	
B	4	4	4		3	3	3	4	4	
C	3	4	4		4	3	3	4	4	
D	4	4	5		4	4	3	4	4	
	Man. Cap.									
	M_1	M_2	M_3	M_4	M_5	M_6				
A	5	4	5	4	4	4,3				
B	5	4	3	4	4	3,3				
C	5	4	4	4	4	4				
D	5	4	3	5	4	4				
	Delivery							Price		
	D_1	D_2	D_3	D_4	D_5	D_6		P_1	P_2	P_3
A	4	4	3	5	4	3,6		4	4	3
B	5	5	5	5	5	5		4	3	4
C	5	5	5	4	4	4		4	4	3
D	5	5	5	5	5	5		3	4	4

4.2. Application of Taguchi loss function

Taguchi method enables us to analyze the tangible values with intangible ones. In this case, "percentage of defective products", "price level" and "delay on delivery" are tangible and measurable criteria while the others are intangible and immeasurable. The specification limits and target values determined by the buyer are listed in table (8). Up to this table, we can say that, 0% defect causes zero loss and 5% defect ratio cause 100% loss.

Table 8. Decision variables for selecting a supplier

	Target value	Specification limit	Range
Defective products	0%	5%	0% - 5%
Price	Minimum	Min + 30%	0% -30%
Delay in delivery	0 Day	15 Days	0 - 15 Days
Other criteria	100%	50%	0% - 50%

Table 9. Characteristic and relative values of suppliers

	Defective products		Price		Delay in delivery	
	Value	Relative value	Value	Relative value	Value	Relative value
A	2%	2%	100%	0%	0	0
B	2%	2%	100%	0%	0	0
C	2%	2%	100%	0%	5	5
D	2%	2%	110%	10%	0	0

Table 10. Conversion table for Taguchi loss function

Score	Percentage score
5	100%
4	80%
3	60%

The real values for measurable criteria and their relative values are listed in table (9). The weights received from ANP solution are combined with Taguchi losses for each criterion. The supplier having the smallest overall loss is named as the best supplier. Since the target value is minimum, "smaller-is-better" Taguchi loss function is used for calculations. The calculation of immeasurable criteria values are based on the unperformed ratio 50% (100% - 50%).

The coefficient "k" values for defect product ratio, price and delay in delivery are found as 40.000; 1,111 and 0,444 respectively by using equation (2). For price criteria $k = 100 / (0, 30)^2$. The k value for immeasurable criteria is 400. After defining k values, the loss for each criterion is calculated with the help of equation (1). For the supplier D, the loss in price criteria is : $L(y) = 1,111.(0,1- 0)^2 = 0,11$.The loss for other criteria is calculated after converting the norm matrix scores into percentage scores by using conversion table that is performed by purchasing team.

The overall Taguchi losses for each supplier are determined by adding the weighted losses of each criterion for that supplier (See table 11). Suppliers are then ranked from the one with the least overall loss. The supplier having minimum loss is the best supplier. Table (12) shows the rank of the suppliers. According to ANP and Taguchi Loss Function decision process, the best supplier is chosen as the supplier "D".

Table 11. Taguchi losses

	Work. Con.			
	W_1	W_2	W_3	W_4
A	16	8	16	16
B	64	46	16	64
C	16	31	16	16
D	16	31	16	16
Weight	0,00764	0,00794	0,00751	0,00857

	Quality			
	Q_1	Q_2	Q_3	Q_4
A	16	16	16	16
B	16	16	0	16
C	16	16	16	16
D	16	16	16	16
Weight	0,10737	0,08196	0,06982	0,06459

	Fin. Status		
	F_1	F_2	F_3
A	16	16	16
B	16	16	16
C	64	16	16
D	16	16	0
Weight	0,02008	0,02058	0,02457

	Env. Health				
	E_1	E_2	E_3	E_4	E_5
A	16	64	64	16	16
B	64	64	64	16	16
C	16	64	64	16	16
D	16	16	64	16	16
Weight	0,02442	0,02442	0,02544	0,03243	0,02725

	Man. Cap.					
	M_1	M_2	M_3	M_4	M_5	M_6
A	0	16	0	16	16	8
B	0	16	64	16	16	46
C	0	16	16	16	16	16
D	0	16	64	0	16	16
Weight	0,00505	0,00499	0,00507	0,00597	0,00530	0,00529

	Delivery					
	D_1	D_2	D_3	D_4	D_5	D_6
A	16	16	64	0	16	31
B	0	0	0	0	0	0
C	0	0	0	22	16	16
D	0	0	0	0	0	0
Weight	0,03083	0,02895	0,03722	0,04750	0,03278	0,02962

	Price		
	P_1	P_2	P_3
A	0	16	64
B	0	64	16
C	0	16	64
D	11	16	16
Weight	0,08480	0,06246	0,05963

Table 12. Ranking for ANP and Taguchi solution

Rank	Supplier	Taguchi loss
1	D	13%
2	B	18%
3	C	20%
4	A	21%

4.3. Application of PROMETHEE method

In this section of the study, PROMETHEE method is used as an alternative way to Taguchi Loss Function for selecting the best supplier. The weights derived from the ANP solution from previous section and the norm matrix scores of suppliers in table (7) are directly used in PROMETHEE functions. The model is analyzed by "Visual PROMETHEE 1.4" software. Usual criterion function is used for analysis. In the flow table (Table 13), "Phi+" and "Phi-" columns are positive and negative flow values respectively. "Phi" column shows us the net flow values of that supplier and the ranking is based on these net flow values. According to PROMETHEE flow table, the best supplier is selected as supplier "D".

Table 13. PROMETHEE flow table

Rank	Supplier	Phi	Phi+	Phi-
1	D	0,1146	0,2304	0,1159
2	B	0,0976	0,2351	0,1375
3	C	-0,0849	0,1126	0,1975
4	A	-0,1272	0,1032	0,2304

5. Conclusion

In literature there are different methods and applications for supplier selection problem. When the problem contains a high number of criteria which are sometimes conflicting, the solution may be too complicated. This study aims to solve a complex supplier selection problem in an effective and easier manner.

AHP and ANP are most frequently used techniques in supplier selection with the usage rates of 24,39% and 12,20% respectively. The multi-attribute utility techniques including AHP and ANP dominate other techniques because of their effectiveness in rating and task choices (Chai et.al, 2013).

In this study ANP method is preferred for determining the weights, since it analyzed not only priorities of the criteria, but also the interrelations between them. The main decision criteria for the case application are "quality", "delivery", "price", "environmental health", "financial status", "managerial capabilities" and "working conditions". ANP analysis gives more accurate results for this complex problem with seven main criteria and thirty one sub-criteria. After defining the weights, two different multi-criteria decision methods, Taguchi loss function and PROMETHEE approaches are used comparatively to find the best supplier and rank the suppliers.

The advantage of Taguchi method is that, it enables to include the measurable and tangible values into the model directly. This method can be important for outsourcing strategic products/services which need sensitive analysis. Because in this model, the specification limits for specific criteria can be used for defining the upper and lower limits. When the company doesn't accept a supplier's score lower than any limit, it can be directly adopted the beginning scale of analysis. Furthermore, in this method, the intervals in the scale are not to be necessarily linear. The method may be shaped for the needs and priorities of each company and product.

The complexity in calculations of Taguchi analysis, brings a need for an easier way to get the same specialized results. The easier and more recent technique is PROMETHEE method. In this study the alternative solution is done by PROMETHEE. The main advantage is that the preference functions make clear the criteria which serve the purpose. This provides to come forward the alternatives that meet the criteria best. PROMETHEE method gives the priorities and weaknesses of alternatives without promise. In the case, the results of PROMETHEE analysis confirm the Taguchi solution results.

As a result of this study, PROMETHEE method can be used in practice for complex and specific supplier selection problems, for the simplicity in its usage.

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