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Supplier selection project using an integrated Delphi, AHP and Taguchi loss function

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Abstract. Supplier selection project is one of the most important decision-making problems for many firms. This paper presents an integrated modified Delphi technique, analytic hierarchy process (AHP) and Taguchi loss functions systems to valuation and selection suppliers. The advantages of these methods are widely acknowledged: increased important performance criteria use in suppliers and improved efficiency in decision-making. Firstly, the criteria has been obtained by Delphi technique including product quality, offering price, on-time delivery, and customer service. Then, major selection criteria are transferred to the Taguchi quality loss and combined AHP based weights for decision-making. Therefore, this work provides an effective decision approach for decision-makers (DMs) to solve a multiple criteria decision-making for supplier selection project problems. A case study application to supplier evaluation and selection is also demonstrated.

Keywords. Supplier selection project, Decision-making, Delphi technique, Analytic hierarchy process (AHP), Taguchi loss functions.

1 Introduction

Project managers are faced with decision environments and problems in projects that are complex (Al-Harbi, [1]). The project of supply chain management has received increasing attention recently (Hwang and Rau, [14]). Companies spend millions of dollars on new management projects in the hope that these projects will allow them to successfully compete in the marketplace (Arbin, [3]). Supplier selection projects are one of the most important of quality, production, and logistics management for many firms. Selection of single or multiple suppliers involves several quantitative and qualitative criteria based on the type of partnership (Awasthi et al., [4]). This selection procedure is essentially considered as a multiple criteria decision-making (MCDM) problem which is affected by different criteria tangible and intangible criteria such as quality, price, delivery, service performance, technical capability, execution time, and so on. For a decision makers (DMs), selecting the right suppliers will significantly reduces purchasing cost, improves competitive ability and increase customer satisfaction. Therefore, DMs need to planned evaluate the suppliers' performance in order to maintain those suppliers can meet company requirement under different evaluation criteria.

A number of evaluation criteria have been proposed to supplier's selection. The criteria have been developed for supplier evaluation and selection problem since1966. Dickson [8] identified 23 different criteria for suppliers selection including quality, on-time delivery, price, performance history, warranties policy, technical capability and financial, and so on. After that, some examples of the supplier selection literature are given as follows. Evans [12] proposed the price, quality and delivery are very important criteria for supplier's valuation in industrial market. Shipley [28] suggested the supplier selection using three criteria including quality, price, and on-time delivery. Ellram [11] believed that in supplier selection process, the firm need to consider the quality, price, delivery and service to meet firm's demand. Weber et al. [32] surveyed the frequency of Dickson 23 criteria; result found a number of using the price, delivery, quality, and productive capability to measure a supplier performance. Tam and Tummala [29] proposed an analytic hierarchy process (AHP) based model and adopted quality, cost, problem solving capability, expertise, delivery lead time, experience, and reputation to selecting a vendor for a telecommunications system. Pi and Low [24] suggested a method for supplier evaluation and selection based on quality, delivery lead time, price and service. Based on their research, which quality, price, delivery, and service are the four most important criteria for supplier evaluation and selection.

Usually, quality is a critical factor for most manufacturers; a high quality supplier has always been an important selected for manufacturing organization (Thompson, [30]); however, it is not enough to promise that the suppliers can avoid addition cost and offer right quality for manufacturer. When manufacturers decrease materials inventory, they will increase the reliance on receiving the "right parts at the right time in the right condition" from their supplier (Lyn et al. [19]). Therefore, a just-in-time (JIT) purchasing system involves the relationship with price, delivery, and service.

In practice, organizational buyers used a variety of methods to assess supplier's price; the purchase price is also a highlighted consideration by the purchasing organization due to it can affect the product pricing. In 1998, 92 percent of buyers responding to a Purchasing magazine survey cited negotiating price as on of their top responsibilities. Nearly as many respondents said price remains a key criterion they use to select supplier (Kotler and Keller, [16]). Therefore, the purchase price or cost is one of evaluation criterion for supplier. For example, Monczka and Trecha [21]) adopted a cost-based supplier performance evaluation model to evaluate key supplier's performance.

Service quality form the supplier is also very important to the manufacturer. Improving service quality is considered an essential strategy for success and survival in today's competitive situation (Pi and Low, [24]). In order to fit the actual needs for customers, it is important in service quality; Li [17]) proposed two modified quality loss function to measure service quality. In addition, the selection of an on-time delivery system is equally an important problem and could involve many criteria, including the technical requirements of delivery specifications and cost, etc. Similarly, performance-related criteria such as delivery reliability, availability and serviceability must also be assessed to meet the service levels as set in service specifications and increase customer satisfaction (Tam and Tummala, [29]).

Miller [20] suggested manufacturers need to look at the supplier organizational two systems; one called process-based evaluation system, including costing, delivery, quality, management and technology; the other called performance-based evaluation system, including supplier's quality and delivery performance. In spite of, the emphasis on supplier evaluation, there are has been little empirical investigation of the supplier evaluation process in terms of the supplier's reaction to it (Lyn et al. [19]). It is important that this study examine all these relevant criteria in selecting a best supplier.

The rest of the paper is organized as follows. Section 2 reviewed the supplier evaluation and selection model. The proposed model is described in Section 3. The theoretic descriptions for modified Delphi technique, AHP and Taguchi loss functions methods are presented sequentially in Section 3.1–3.3. Section 4 presents application of the integrated model to the supplier selection problem as a real word case study. Finally, the results are provided and the paper is concluded in Section 5.

2 Supplier selection method

In previous research, there are many literature has accumulated on the subject of supplier evaluation and selection. Most of these models finalize the supplier selection decision-making process based on a set of supplier performance criteria (Youssef et al. [34]; Pi and Low, [24]). They can be summarized as following:

2.1 Cost-ratio method

The cost-ratio method evaluates the cost each attribute as a percentage of the total purchase for the suppler. Summing these percentages and assign to the price percentage, DMs can obtain the total price of the purchasing parts. Nevertheless, this approach has difficulties in developing cost accounting systems for purpose (Timmerman, [31]).

2.2 Cost-based models

According to Monczka and Trecha [21] recognized that material price is only a fraction of the cost of the purchased material in this model. In cost-based the suppliers' performance evaluation system reflects the actual total cost of doing business with suppliers. They developed two indexes for their cost-based model, namely service factor rating (SFR) and supplier performance index (SPI). Before calculating these two indexes, the evaluated key items and performance parameters should be identified.

Youssef et al. [34] recognized the cost-based model has three advantages. First, it allows for qualitative and quantitative evaluation criteria. Second, the evaluation on qualitative criteria is done by those who have direct contact with suppliers; Third, the two indexes are complementary to each other and, if integrated properly, would make this model supplier to other available models. However, with this and other models, the process of evaluation is still subjective.

2.3 Categorical models

Willis and Houston [33] proposed the categorical model; suppliers are evaluated on criteria such as quality, cost, speed of delivery, etc. Base on each criteria, the suppliers were classified to good-, fair-, bad-level, and were assigned a (+), (0) or (−) to each level, respectively. A suppler will be the best one if it gets more (+) than another. The limitation of this model is that all the attributes are weighted equally. Distinctly, this method is intuitive, subject, simplistic in nature but is easy to use. Youssef et al. [34] suggested that the model can be useful if a weight are assigned to each attribute and the (+), (0) and (−) are replaced with (+1), (0) and (−1), respectively. The DMs based on the total score, suppliers then can be ranked and the supplier with the highest score will be selected.

2.4 Weighted point method

The weighted point models are expressed as follows (Willis and Houston, [33])

$$S_j = \sum_{i}^{n} w_i p_{ij} \tag{2.1}$$

where S_i is summated score to represent the total performance anticipated from vendor j; w_i is importance weight attached to evaluative criteria i; p_{ij} denoted the performance rating on evaluative criteria i for supplier j; and n is the number of evaluative criteria.

To use the above model, the criteria of supplier evaluation must be identified and assigned the weight point in the beginning. Then the related purchasing people will rate the supplier's performance under intuitive judgment. Thompson [30] pointed out that the mathematics underlying weighted point decision. However, weighted point models also have some disadvantages. One major disadvantage is the limitations associated with scaling techniques.

2.5 Vendor profile analysis

Vendor profit analysis is a modified weighted point model (Thompson, [30]). Using Thompson's notations (see Equation (2.1)) the vendor profit analysis model can be expressed as follows:

$$S_{jk} = \sum_{i}^{n} w_i p_{ijk} \tag{2.2}$$

where S_{ik} is summated score for vendor j on iteration k of the simulation; w_i is importance weight attached to evaluative criteria i; p_{ijk} denoted the performance rating on evaluative criteria i for vendor j during iteration k from simulation; and n is the number of evaluative criteria.

The Monte Carlo simulation technique have used in this model for modelling the uncertainty associated with predicting vendor performance against the evaluative criteria instead of rating from human intuitive judgment. The simulation algorithm randomly samples values p_{ijk} from within each estimated performance range and then combines these values with importance weights, in accordance with linear compensatory rules, to produce a distribution of summated scores. Each computer generated S_{jk} amounts to a single iteration of the simulation process. This process is repeated up to several thousand times for each vendor (Pi and Low, [24]). The approach of Monte Carlo simulation can simplifies the DMs' input to the model evaluation and provides output that includes more information upon which to base purchase decisions than do standard weight point decision models.

2.6 Dimensional analysis

The evaluation process of supplier involves a series of one-on-one comparisons and can only compare two vendors each time under dimensional analysis method. The dimensional analysis ratio (DAR) can be obtained from Equation (2.3).

$$\mathrm{DAR} = \prod_{i=1}^{n} (\frac{A_i}{B_i})^{R_i}, \quad i = 1, 2, \ldots, n^{\mathrm{th}} \text{ attribute} \tag{2.3}$$

where A_i and B_i represent ith attribute score of entity A and B, respectively, and R_i is a relative importance assigned to attribute i.

Then, the values of DAR there are three cases; (1) DAR $>$ 1, (2) DAR $=$ 1 or (3)DAR $<$ 1. For example, if in the first case, denoted ranks vendor A higher than vendor B, and so on. However, there are two disadvantages in this model. First, a value of $DAR = 1$, it will cause the DM to be indifferent about which vendor to chose. Second, the process becomes very tedious and time consuming if a large number of vendors can be selection (Youssef et al. [34]).

Although these current models has been adopted to solving the multi-attribute/multi-criteria decision-making problems. However, the situation of "the more/higher is better in the criteria" (*e.g.*, service satisfaction) and "the less/lower is better in the criteria" (*e.g.*, product quality loss, price loss and delivery loss) can not be solved by above models or methods, simultaneously. This problem can be solved by the proposed method.

3 The proposed method

The proposed method consists of the modified Delphi technique, AHP and Taguchi loss functions. The evaluation procedure of the supplier selection project is show in Fig. 1. The first step is to identify the multiple criteria that are considered in the decision-making process for the DMs to make an objective and unbiased decision. Nine experts were gathered to form a panel and, then, the modified Delphi technique was used to define the evaluative criteria and establish a hierarchical model with supplier selection. After constructing the relationship of criteria network structure, the weights can be calculated by applying AHP. Finally, we conducted a Taguchi loss function approach to achieve the final ranking results. The detailed descriptions of the major steps are elaborated in each of the following subsections.

3.1 Modified Delphi technique

The Delphi technique is a conventionally adopted qualitative forecasting method (Anderson, [2]), which involves the systematic application and colla-

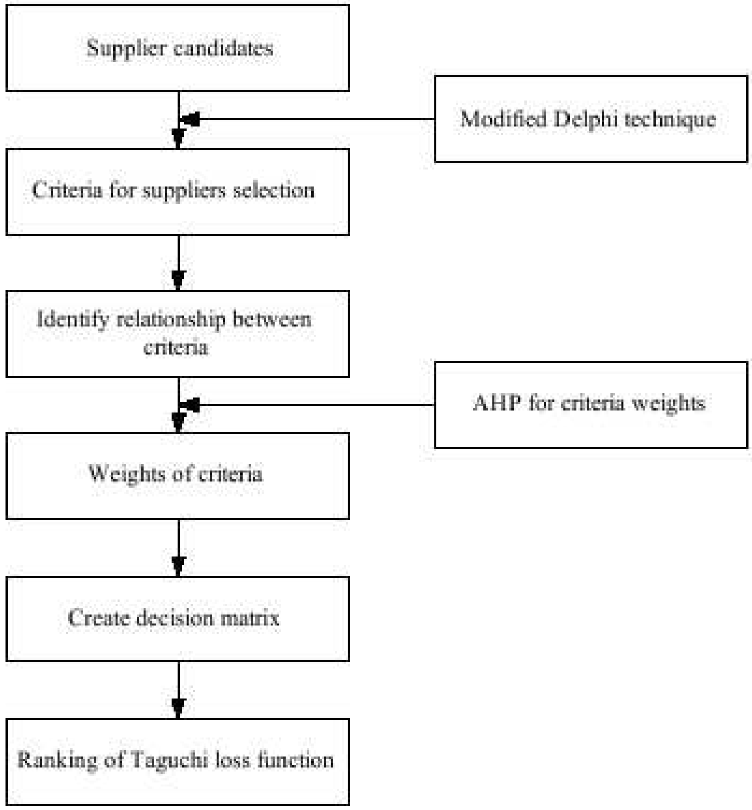

Figure 1: The supplier selection project process

tion of experts on a particular issue through a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions derived from earlier response (Delbecq et al. [7]). The originally developed by a research group at the Rand Corporation, Delphi technique attempts to forecast current trends through a group consensus (Hsu and Chen, [13]). Furthermore, experts are anonymous and do not meet each other in person. Dijk [9] point out the Delphi technique is a suitable communication technique on the subjective base of norms and opinions for social research. In addition, Dijk [9] adopted Delphi to solve the problem of introduce a largely scale automation of commercial bank work. Chaw [5] applied the Delphi to select procurement system for construction project.

In addition, Murry and Hammons [22] modified the traditional Delphi technique by eliminate the first-round questionnaire containing unstructured questions. Besides saving time and expenses, a structured questionnaire allows the panel to immediately focus on the study issues. Hsu and Chen [13] adopted the modified Delphi technique to develop and implement a selection model for chain store. Therefore, this work will adopt the modified Delphi technique based on results of literature review and interviews with experts to select the probably criteria. Although between 5 and 20 experts should be used in experts forecasting (Anderson et al. [2]), group size influences the effectiveness of group decision-making. Thus, the decision-making group probably should not be too large; for example, a minimum of 5 to a maximum of about 50 (Robbins, [25]), the Delphi Technique work group of five to nine members. Therefore, this work invited nine experts to particulate in the modified Delphi technique group discussion.

3.2 The AHP

The analytic hierarchy process (AHP) is a multi-attribute decision tool that allows financial and non-financial, quantitative and qualitative measures to be considered and trade-offs among them to be addressed. The AHP is aimed at integrating different measures into a single overall score for ranking decision alternatives (Önü and Soner, [23]). Its main characteristic is that it is based on pair-wise comparison judgments. The description is developed in three steps (Saaty, [27]):

Step 1: Compose a pair-wise comparison decision matrix.

Let A represent $a^{n\times n}$ pair-wise comparison matrix and can be expressed as

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \tag{3.1}$$

where $a_{ij} = 1$ and $a_{ij} = \frac{1}{a_{ji}}$, $i, j = 1, 2, \ldots, n$. Let $C_1, C_2, \ldots, C_n$ denote the set of criteria, while a_{ij} represents a quantified judgment on a pair of criteria C_i and C_j. Saaty [27] constitutes a measurement scale for pair-wise comparison. The values of 1, 3, 5, 7, and 9 represent equal importance, weak importance, essential importance, demonstrated importance and extreme importance, respectively; while the values of 2, 4, 6, and 8 are used for compromise between the above values.

Step 2: Calculate the importance degree.

The normalization of the geometric mean (NGM) method is used to determine the importance degrees of DMs requirements. Let W_i denoted the importance degree (weight) for the ith criteria, then

$$W_i = \frac{\sqrt[n]{\lambda_{j=1}^{n} a_{ij}}}{\sum_{i=1}^{n} \sqrt[n]{\lambda_{j=1}^{n} a_{ij}}}, \quad i, j = 1, 2, \ldots, n. \tag{3.2}$$

where n is numerical criteria.

In addition, the maximal eigenvalue $\lambda_{\max}$ can be calculated by Equation (3.3) and (3.4)

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1\cdots & a_{2n} & \\ \vdots & & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} * \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} W_1' \\ W_2' \\ \vdots \\ W_n' \end{bmatrix}, \tag{3.3}$$

$$\lambda_{\max} = (1/n) * (W_1'/W_1 + W_2'/W_2 + \cdots + W_n'/W_n). \tag{3.4}$$

Step 3: Do consistency analysis.

Then the maximal eigenvalue $\lambda_{\max}$, a consistency index (CI) can be calculated by

$$\text{CI } = \lambda_{\max} - n/n - 1. \tag{3.5}$$

In Equation (3.5), If CI = 0, the evaluation for the pair-wise comparison matrix is implied to be completely consistent. Particularly, the closer of the maximal eigenvalue is to n the more consistent the evaluation is. Generally, a consistency ratio (CR) can be used as a guidance to check for consistency.

The formulation of CR is:

$$\text{CR} = \text{CI}/\text{RI} \tag{3.6}$$

where RI is the average random index with the value obtained by different orders of the pair-wise comparison matrices. If CR is less than 0.1, the judgments are consistent, so the derived weights can be used.

3.3 Taguchi loss functions

Taguchi's loss function is famous as a useful method in the area of quality control. In traditional systems, the product is accepted if a product measurement falls within the specification limit; otherwise, the product is rejected. The quality losses occur only when the product is of unacceptable quality (Pi and Low, [24]). Taguchi defines the quality as 'the loss imparted by any product to society after being shipped to a customer, other than any loss caused by its intrinsic function' (Ross, [26]). By "loss", Taguchi refers to the two categories; loss caused by variability of product functional performance, and loss caused by harmful side-effects (Cho and Cho, [6]). Therefore, Taguchi propose a more narrow opinion of characteristic acceptability to indicate that any deviation from a characteristic's target value results in a loss. For example, the loss is zero, when the characteristic's measurement is the same as the target value. Kethley and Waller [15] believe that the loss can be measured using a quadratic function and action are taken to reduce systemically the variation from the target value.

Taguchi's loss function is classified into three types of functions: nominal-is-best characteristics, smaller-is-better characteristics and lager-is-better characteristics. The proper function depends on the magnitude of variation and the variation is allowed in both directions from the target value. This target can be the centre within two-sided specification limits, called the two-sided equal or nominal-is-best loss function (see Fig. 2 [32]. The loss function can be expressed as follows:

$$L(y) = k(y - m)^2 \tag{3.7}$$

$$L(y) = k_1(y - m)^2 \text{ or } L(y) = k_2(y - m)^2 \tag{3.8}$$

where $L(y)$ is the loss associated with a particular value of equality character y, m is the nominal value of the specification, k, k_1 or k_2 is the loss coefficient and the value is a constant depending on the cost at the specification, limits and the width of the specification.

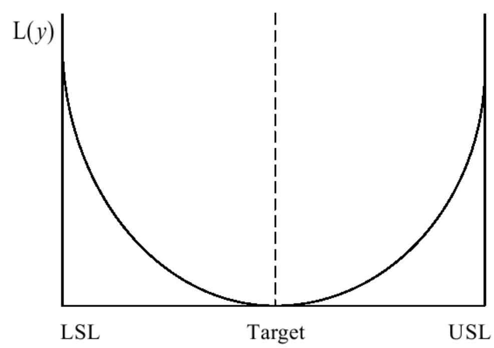

Figure 2: Nominal-is-better loss function

In addition, the other two loss functions are the one-sided minimum specification limit and one-sided maximum specification limit function, called smaller-is-better loss functions and larger-is-better loss functions (see Fig. 3 and Fig. 4). The two loss functions can be expressed as Equation (3.9) and Equation (3.10), respectively.

$$L(y) = k \cdot (y)^2 \tag{3.9}$$

$$L(y) = k/y^2 \tag{3.10}$$

where the all variable defined or calculation as the same in nominal-is-best loss function.

In recent years, Taguchi loss function has been paid attention by researcher; such as Kethley and Willer [15] adopted it to improver customer service in the real estate industry. On the other hand, Li [17] applied it for the measurement of service quality.

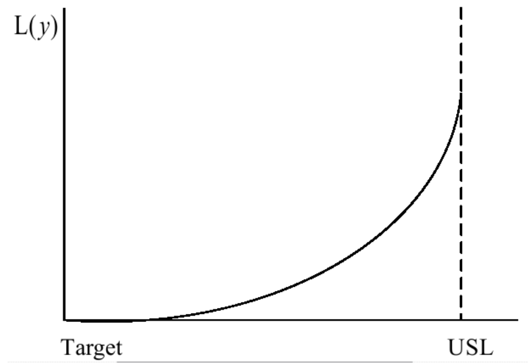

Figure 3: Smaller-Is-Better loss function

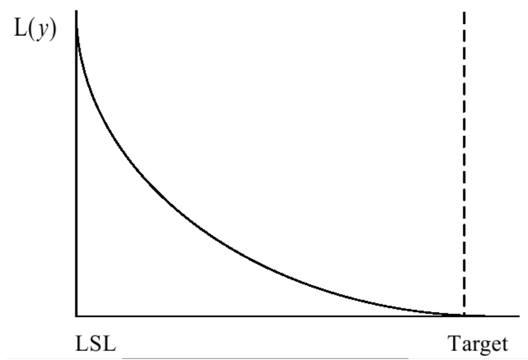

Figure 4: Larger-Is-Better loss function

4 A case application

This study establishes and demonstrates the effectiveness of a food manufacturer supplier selection model. The case company Hunya Foods CO., LTD. (HFCL) is a large, well-known manufacturing firm that sells foods in its own chain stores in Asia. Its board wishes to select a material supplier to purchase key components for new products in order to achieve a better competitive advantage in the Chinese market. However, the company lacks an objective means of selecting the most promising supplier. Therefore, a DM group for supplier selection is organized, including four of the following: chief executive officer, business manager, marketing manager and purchase manager. This study selected the criteria identified from previous literature and interviews with experts. Nine experts participated in a group that applied the modified Delphi technique. The questionnaire was send using e-mail; the evaluation and selection were defined; the final criteria was extracted in whish a score of four on the Likert 5-point scale must be achieve; and the results were collected after passing two rounds of using the modified Delphi technique.

Based on the results of group decision-making and modified Delphi technique that there are five suppliers can be selection and there are four criteria being used to evaluate the suppliers: quality, price, delivery and service. For quality, HFCL set the percentage target of defect parts at zero and the upper specification limit could be set 2% to indicate the allowable deviation from the target value. Zero loss will occur for zero percent defective parts and 100% loss will occur at the specification limit of 2% defective parts. For price, the loss will be zero at the lowest supplier and the specification limit is up 15% of the lowest price by HFCL required. The loss will be 100% as the price reaches the specification limit. For delivery, HFCL set the specification limit of delivery delay is three working days, meaning that 100% loss occur if the supplier's delivery delay is three working days.

For supplier's service, the factor is not easy to quantify. Monczka and Trecha [21] proposed a service factor rating (SFR) to measure the supplier service performance. The SFR includes performance factors that are difficult to quantify from a cost point of view, but they are important to the supplier's success. These factors include ability of problem's resolve, availability of technical data, forwarding of correlation data, ongoing progress reporting, responsiveness to return authorization, and supplier response to corrective action (Pi and Low, [24]). For a given supplier, then, his ratings on all factors are summed, and then averaged to gain a total service rating. This figure is then divided by the total number of points possible, to gain the supplier's service factor percentage (Monczka and Trecha, [21]). For group decision-making, HFCL set the specification limit of the supplier's service factor percentage is 60%. At this time, the loss will be 100%. Also zero loss will occur if the supplier's service factor percentage is 100%. The target value, the specification limit, and the range value of the allowable deviation for each decision variable are showed in Table 1.

Table 1: Decision variables for supplier's selection

	Target value	Specification limit	Range
Quantify	0%	2%	0% ∼ 2%
Price	0% lowest	15% higher	0% ∼ 15%
Delivery	0	3	0 ∼ 3
Service	100%	60%	100% ∼ 60%

For calculating the value of average quality loss coefficient, say, k, from Equation (3.9) or Equation (3.10), the dataset is calculated from 200 data fields and 15,386 records of suppliers by HFCL. We given the quality, price, delivery, and service average quality loss coefficient (k) were 24500, 2400, 1.45 and 25, respectively. For supplier S2, the quality value is 1.8% defective rate, which relates to 1.8% deviation from the target value. In other words, the relative value in Table 2 is entered into the Equation (3.9) or Equation (3.10), as the value with the constant k previously calculate for these four characters, resulting in the Taguchi loss. The results of Taguchi loss function for these four evaluation characteristics for five suppliers are shown in Table 3.

Supplier	Quality		Price		Delivery		Service	
	Value	Relative value	Value	Relative value	Value	Relative value	Value	Relative value
S1	1.60%	1.60%	110%	10.00%	2.00	2.00	95.00%	95.00%
S2	1.80%	1.80%	100%	0.00%	2.50	2.50	82.00%	82.00%
S3	1.00%	1.00%	105%	5.00%	2.50	2.50	75.00%	75.00%
S4	1.50%	1.50%	108%	8.00%	1.50	1.50	70.00%	70.00%
S5	1.40%	1.40%	115%	15.00%	2.00	2.00	65.00%	65.00%

Table 2: Characteristic and relative values of suppliers

By the AHP applications, the DMs of HFCL have to indicate preferences or priority for each decision supplier in terms of how it contributes to each criterion as showed in Table 4. In AHP computation, the largest eigenvalue $\lambda_{\max}$ of this comparison matrix is 4.265, the weights of these four criteria being 0.487, 0.105, 0.275, and 0.133 for quality, price, delivery, and service, respectively. Now, we found the consistency index, CI = 0.0883 and selecting appropriate value of random consistency ratio, RI, for a matrix size of four by Saaty [27]), we find RI = 0.9. We then calculate the consistency ratio, CR = 0.0981. As the value of CR is less than 0.1, the judgments are acceptable.

Finally, the weighted Taguchi loss can be determined for these five suppliers, its ranking begins as presented in Table 5. The ranking order of the five suppliers from total Taguchi loss are S2 > S5 > S1 > S4 > S3. Therefore, the HFCL can conclude that the supplier "S3" will be the best selection from Delphi expert's technique, AHP weights and Taguchi loss function process.

5 Conclusion

The project of supplier selection is a MCDM problem in decision-making management. This paper proposed a supplier evaluation and selection method via modified Delphi technique, AHP and Taguchi loss functions to increase the decision-making efficiency. The case selected the criteria are quality, price, delivery, and service identified from a group decision adopted the modified Delphi

Supplier	Quality	Price	Delivery	Service
S1	62.72	24.00	5.80	27.70
S2	79.38	0.00	9.06	37.18
S3	24.50	6.00	9.05	44.44
S4	55.13	15.36	3.26	51.02
S5	48.02	54.00	5.80	59.17

Table 3: Supplier characteristic Taguchi loss

	Quality	Price	Delivery	Service	Weights
Quality	1.0	2.5	3.0	4.0	0.487
Price	0.4	1.0	0.3	0.5	0.105
Delivery	0.3	3.0	1.0	3.0	0.275
Service	0.3	2.0	0.3	1.0	0.133

Table 4: Pair-wise comparison matrix of the four criteria

Supplier	Quality Taguchi loss	Price Taguchi loss	Delivery Taguchi loss	Service Taguchi loss	Total Taguchi loss	Supplier selection ranking
S1	62.72	24.00	5.80	27.70	38.344	3
S2	79.38	0.00	9.06	37.18	46.095	5
S3	24.50	6.00	9.05	44.44	20.965	1
S4	55.13	15.36	3.26	51.02	36.142	2
S5	48.02	54.00	5.80	59.17	38.521	4

Table 5: The weight Taguchi loss and ranking of supplier

technique. Criteria weights are derived by AHP-based on pair-wise comparison to describe the DMs' preference for each criterion. The performance of each criterion for each supplier has been transferred to quality loss by using Taguchi loss function. The results guide the DMs to selection the best supplier among the candidates.

This work provides an objective and effective decision method for DMs to solve the others MCDM problems; for example, marketing project planning, project consultant selection, human development projects, and so on. The advantage of this method is that it allows DMs to set multiple aspiration levels for supplier selection problems in which "the more/higher is better" (*e.g.*, benefit factors) or "the less/lower is better" (*e.g.*, cost factors). Furthermore, using a group decision-making mathematical model can be very useful in future research. In other words, the mathematical models; such as analytic network process (ANP), techniques for order preference by similarity to ideal solution (TOPSIS), fuzzy goal programming (FGP), multi-choice goal programming (MCGP), and multi-segment goal programming (MSGP) (*e.g.*, Liao, [18]) can be combined with the existing method.

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