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ORIGINAL ARTICLE

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Supplier evaluation and selection using Taguchi loss functions

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Abstract The purchasing function directly affects the competitive ability of a firm. Purchasing managers need to periodically evaluate supplier performance in order to retain those suppliers who meet their requirement. Four attributes are frequently used as performance criteria. These attributes are quality, on-time delivery, price and service. An evaluation and selection system of suppliers using Taguchi loss functions is proposed in this paper based on these four attributes. These four attributes are transferred to the quality loss and combined to one decision variable for decision making. It is useful to make supplier evaluation and selection for promoting the competitive ability of a firm. An example of application to supplier evaluation and selection is also presented.

Keywords Price, Service · Quality, Delivery · Supplier Evaluation · Taguchi loss functions

1 Introduction

Quality is a critical concern for most manufacturers. The need for high quality suppliers has always been an important issue for many manufacturing organizations [1] but it is not enough to consider only that the suppliers can provide good quality parts. When manufacturers reduce their materials inventory, they increase their reliance on receiving the "right parts at the right time in the right condition" from their suppliers [2]. Especially, a just-in-time purchasing or delivery system refers to the relationship between suppliers and manufacturers.

Usually the purchasing price is also a highlighted consideration to the purchasing organization but the purchase price is only a fraction of the cost associated with material receipt. When a supplier fails to meet delivery, quality and price requirements, additional costs are required by the purchasing organization to correct these deficiencies. So, purchasing's focus must shift from primarily a unit-price-oriented to a cost-based-performance evaluation of suppliers. Monczka and Trecha (1988) provided a cost-based supplier performance evaluation system to evaluate key supplier performance.

Improving service quality is also considered an essential strategy for success and survival in today's competitive situation. In order to meet the actual needs of customers, it is important to quantify service quality. Li (2003) proposed two modified quality loss functions to measure service quality.

The purchasing department may try to find the optimal supplier - not necessarily the supplier offering the best technical service, the lowest price or the shortest delivery. The purchasing function directly affects the ability of a firm to compete through its impact on quality, cost, technology and supplier responsiveness. So firms have been encouraged to developed longer-term trust-based relationships with fewer suppliers [5]. At this time, supplier selection is one of the most important phases of the purchasing process. Once an acceptable supplier is identified, the buyer has an opportunity to establish a long-term relationship with the supplier, which may provide a strategic advantage [5].

Within many sectors of manufacturing, the evaluation of suppliers has become a more common activity. Manufacturers have been looking at the supplier organization's systems for costing, delivery, quality, management and technology, called process-based evaluations, or looking at the supplier's quality and delivery performance, called performance-based evaluations [6]. Despite the emphasis on supplier evaluation, there has been little empirical investigation of the supplier evaluation process in terms of the suppliers' reaction to it [2].

In this paper, we develop a simple method for supplier evaluation and selection based on quality, on-time delivery, price and service. The model quantifies these four attributes in terms of Taguchi quality loss and then combines them into one global decision variable for decision making. A numerical example is also presented to illustrate the model and to show its utility.

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2 Supplier evaluation model review

A lot of literature has accumulated on the subject of vendor evaluation and selection models. Most of these models finalize the supplier selection decision-making process based on a set of supplier performance criteria [7]. They are summarized in the following:

2.1 Categorical models

In the categorical model [8], suppliers are evaluated on criteria such as cost, quality, speed of delivery, etc. Against each criteria, suppliers were classified to good, fair, bad and were assigned a (+), (0) or (−) to each level, respectively. A supplier will be the best one if it gets more (+) than another. The limitation with this approach is that all the attributes are weighted equally. Apparently, this approach is intuitive, subject, simplistic in nature and is easy to use.

Alternatively, the method can be useful if weights are assigned to each attribute and the (+), (0) and (−) are replaced by (+1), (0) and (−1), respectively. Based on the total score, suppliers then can be ranked and the supplier with the highest score will be selected [7].

2.2 Cost-ratio method

The cost ratio method evaluates the cost of each attribute as a percentage of the total purchase for the supplier. Summing these percentages and adding to the price percentage, we can get the total price of the purchasing parts. However, this approach has difficulties in developing cost accounting systems for this purpose [9].

2.3 Cost-based models

This model recognizes that material price is only a fraction of the cost of the purchased material [3]. According to Monczka and Trecha (1988), a cost-based supplier performance evaluation system reflects the actual total cost of doing business with suppliers. They developed two indexes for their cost-based model, namely supplier performance index (SPI), and service factor rating (SFR). Before calculating these two indexes, the evaluated key items and performance parameters should be identified. This model has several advantages [7]. 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 superior to other available models. However, with this and other models, the process of evaluation is still subjective.

2.4 Weighted point method

In general, weighted point models are formulated as follows [10]:

$$A_j = \sum_{i=1}^{n} a_i b_{ij} \quad (1)$$

where:

A_j = Summated score to represent the total performance anticipated from vendor j.
a_i = Importance weight attached to evaluative criterion i.
b_{ij} = Performance rating on evaluative criterion i for vendor j.
n = Number of evaluative criteria.

To use the weighted point method, the criteria of vendor evaluation must be identified and assigned the weight point in the beginning [8]. Then, the related purchasing people will rate the suppliers' performance under intuitive judgment. Thompson (1991) pointed out that the mathematics underlying weighted point models is simple; they can be adapted to any type of purchase 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 profile analysis is a modified weighted point model [10]. Using Thompson's notations, the vendor profile analysis model can be written as follows:

$$A_{jk} = \sum_{i=1}^{n} a_i b_{ijk} \quad (2)$$

where:

A_{jk} = Summated score for vendor j on iteration k of the simulation.
a_i = Importance weight attached to evaluative criterion i.
b_{ijk} = Performance rating on evaluative criterion i for vendor j during iteration k from simulation.
n = Number of evaluative criteria.

This model uses the Monte Carlo simulation technique 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 (b_{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 A_{jk} amounts to a single iteration of the simulation process. This process is repeated up to several thousand times for each supplier. The use of Monte Carlo simulation simplifies decision makers' input to the evaluation model and provides output that contains considerably more information upon which to base purchase decisions than do standard weighted point decision models.

2.6 Dimensional analysis (DA)

In this model, the evaluation process involves a series of one-on-one comparisons and can only compare two suppliers each time. The dimensional analysis ratio is obtained from equation:

$$DA = \prod_{i=1}^{n} \left(\frac{X_i}{Y_i}\right)^{W_i} \quad (3)$$

where:

X_i = ith attribute score of entity X.
Y_i = ith attribute score of entity Y.
i = 1, 2, ... , nth attribute.
W_i = Relative importance assigned to attribute i.

Then, the value of DA can be bigger than 1, equal to 1 or less than 1. The first case, DA is bigger than 1, ranks supplier X higher than supplier Y, and so on. Youssef et al. (1996) pointed out that this evaluation method has two disadvantages. First, a value of $DA = 1$ will cause the decision maker to be indifferent about which supplier to chose. Second, the process becomes very tedious and time consuming if a large number of suppliers can be chosen.

3 Proposed model

Based on the past research, four salient attributes are important in supplier selection. They are quality, on-time delivery, price and service. So in this paper, we incorporate these four valuable attributes in terms of loss using the Taguchi loss function and then combine them into one global decision variable under the weighted consideration.

3.1 Taguchi loss functions

In traditional systems, if a product measurement falls within the specification limit, the product is accepted; otherwise the product is rejected. The quality losses occur only when the product is of unacceptable quality - when it deviates beyond the quality specification limit. These costs tend to be constant and relate to the costs of bringing the product back into specification range. Taguchi suggests a more narrow view of characteristic acceptability and indicates that any deviation from the characteristic's target value results in a loss. If a characteristic measurement is the same as the target value, the loss is zero. Otherwise, the loss can be measured using quadratic functions and actions are taken to reduce systemically the variation from the target value [12]. Taguchi's formulation recognizes the losses before a product is shipped, the losses incurred during use, and most important, losses incurred as a result of use or consumption [13].

There are three types of loss functions that may be used [14]. The first one is the nominal value, the best value. 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 or some shift within two-sided specification limits, called the two-sided equal specification Taguchi loss function and the two-sided with specification preference Taguchi loss function, respectively, (see Figs. 1 and 2) [12]. The loss function can be shown as Eqs. 4 or 5:

$$L(y) = k(y-m)^2 \quad (4)$$

$$L(y) = k_1(y-m)^2 \quad \text{or}$$
$$L(y) = k_2(y-m)^2 \quad (5)$$

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

The other two functions are the one-sided minimum specification limit and the one-sided maximum specification limit function, called smaller is better, higher is better (see Figs. 3 and 4) [12]. The loss function can be shown as Eqs. 6 and 7,

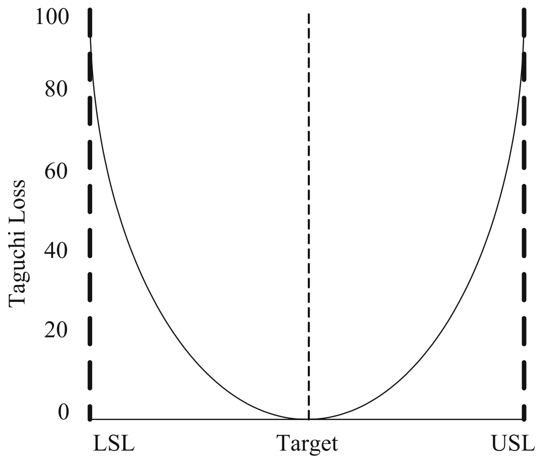

Fig. 1. Two-sided equal specification Taguchi loss function

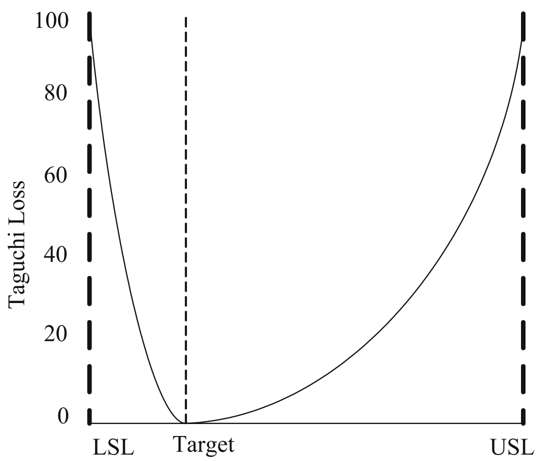

Fig. 2. Two-sided with specification preference Taguchi loss function

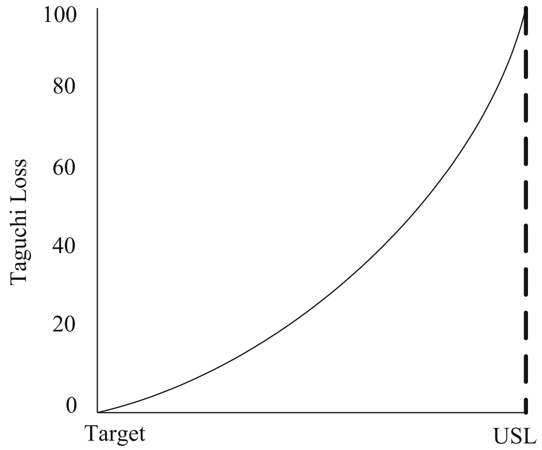

Fig. 3. Smaller is better Taguchi loss function

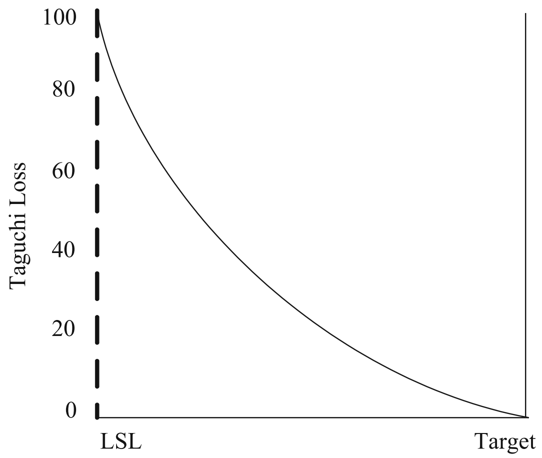

Fig. 4. Higher is better Taguchi loss function

respectively:

$$L(y) = k(y)^2 \tag{6}$$

$$L(y) = k/y^2 \tag{7}$$

where the meanings or calculation of $L(y)$, y and k are the same as in Eq. 4.

Taguchi loss functions have been used for non-manufacturing applications recently. Quigley and McNamara (1992) implemented it to evaluate product quality as an aid to the selection of suppliers. Kethley (2002) applied it to improve customer service in the real estate industry. Li (2003) used it for the measurement of service quality.

3.2 Suppliers' evaluation and selection using Taguchi loss functions

To illustrate how Taguchi loss functions can be used to select and prioritise suppliers, the following example is provided. Suppose a manufacturer has four suppliers for some component and this manufacturer wants to rank these suppliers or select one from them. For quality, the manufacturer could set the percentage target of defect parts at zero and the upper specification limit could be set at 3% 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 3% defective parts. For on-time delivery, the manufacturer will have a lot of loss if the supplier delays delivery of the parts and will have a lower loss if the supplier delivers the parts prior to the schedule requirement. This variation is allowed in both directions from the target value and could be set using the two-sided model with specification preference function. But in practice, the lead-time is short and the loss for delayed deliveries always catches more attention. The higher property will be applied to the model and the specification limit of delivery delay is three working days, meaning that 100% loss will occur if the supplier's delivery delay is three working days. For price, the loss will be zero at the lowest supplier and the specification limit is up to 20% of the lowest price. The loss will be 100% when the price reaches the specification limit. The service factor is not easy to quantify. Monczka and Trecha (1988) 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

Table 1. Decision variables for selecting supplier

	Target value	Range	Specification limit
Quality	0%	0%–3%	3%
On-time delivery	0	0–3	3
Price	lowest	0 ∼ 20%	20% higher
Service	100%	100% ∼ 50%	50%

Table 2. Supplier's characteristic value and relative value

	Quality		On-time delivery		Price		Service	
Supplier	Value	Relative value	Value	Relative value	Value	Relative value	Value	Relative value
A	2.50%	2.50%	2.00	2.00	110.00	10.00%	90.00%	90.00%
B	1.80%	1.80%	2.50	2.50	108.00	8.00%	72.00%	72.00%
C	1.20%	1.20%	2.50	2.50	100.00	0.00%	65.00%	65.00%
D	2.80%	2.80%	1.50	1.50	118.00	18.00%	95.00%	95.00%

Table 4. Weighted Taguchi loss and its ranking

Supplier	Quality weight	Quality Taguchi loss	On-time delivery weight	On-time delivery Taguchi loss	Price weight	Price Taguchi loss	Service weight	Service Taguchi loss	Weighted loss	Supplier ranking
A	0.40	69.44	0.35	44.44	0.15	25.00	0.10	30.86	50.17	3
B	0.40	36.00	0.35	69.44	0.15	16.00	0.10	48.23	45.93	2
C	0.40	16.00	0.35	69.44	0.15	0.00	0.10	59.17	36.62	1
D	0.40	87.11	0.35	25.00	0.15	81.00	0.10	27.70	58.51	4

success. These factors include ability to resolve problems, availability of technical data, forwarding of correlation data, ongoing progress reporting, responsiveness to return authorization and supplier response to corrective action. In practice, the related personnel such as purchasing, quality control, manufacturing and product engineering can rate for these performance factors. The rating reflects the individual's actual experience with the supplier, and it is to a great extent a subjective assessment. For a given supplier, then, his ratings on all factors are summed, and then averaged to obtain a total service rating. This figure is then divided by the total number of points possible, to obtain the supplier's service factor percentage [3]. Suppose the specification limit of the supplier's service factor percentage is 50%. At this time, the loss will be 100%. Also zero loss will occur when the supplier's service factor percentage is 100%. Table 1 indicates the range value and the specification limit, as well as the relative range of the allowable deviation for each of the decision variables.

Calculating the value of k from Eqs. 6 or 7 gives a value of 111 111.11, 11.11, 2500 and 25 for quality, on-time delivery, price and service, respectively. Table 2 provides the characteristic value and relative value for four suppliers. For supplier 1, the quality value is 2% defective rate, which relates to 2% deviation from the target value. The relative value from Table 2 is entered into the Eqs. 6 or 7, as the value with the constant k previously calculated for these four characters, resulting in the individual Taguchi loss. The outputs of Taguchi loss function for these four evaluation characteristics for four suppliers are presented in Table 3.

Now, the Taguchi loss function results in four separate loss measurements for each supplier. In practical applications, a single value is desirable in order to allow comparison of the utility of various suppliers. These four losses can be considered of equal importance and added together for comparison. But general speaking, this is unfair. So, losses generated by Taguchi loss function can be weighted to represent the relative importance

Table 3. Supplier characteristic Taguchi loss

Supplier	Quality	On-time delivery	Price	Service
A	69.44	44.44	25.00	30.86
B	36.00	69.44	16.00	48.23
C	16.00	69.44	0.00	59.17
D	87.11	25.00	81.00	27.70

of each measurement according to the rating from the related personnel. The weighted Taguchi loss can then be calculated as Eq. 8:

$$Loss = \sum_{i=1}^{n} W_i C_i \tag{8}$$

where W_i is the weight assigned to characteristic i and C_i is the Taguchi loss of characteristic i. Ranking the suppliers from the smallest to the largest loss can then be done. Suppose, the manufacturer ranks quality as the top priority and the weights in these four attributes are set to 0.40, 0.35, 0.15 and 0.1 for quality, on-time delivery, price and service, respectively. The weighed Taguchi loss can be determined for these four suppliers and its ranking is shown in Table 4. We can conclude that supplier "C" will be the best selection from the loss function and weighted combination.

4 Conclusions

A supplier evaluation and selection system using the Taguchi loss function is proposed in this paper. It addresses the issue of how to measure overall supplier performance on the basis of quality, on-time delivery, price and service. As purchasing organizations continues to secure longer-term supplier relationships, this evaluation program can address buying needs by monitoring and evaluating suppliers on their actual performance. It communicates the purchasing priorities to the supplier in a situation that is easy to understand.

In real applications, some of the potential issues that managers may encounter are selection of appropriate inputs and decision of weight for each characteristic. Managers must carefully evaluate and select the factors that best represent their competitive priorities, goals and objectives. This will make the model application more robust and realistic.

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