

Strategic sourcing: a combined QFD and AHP approach in manufacturing

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1. Introduction

Supply chain management (SCM) is the process of planning, implementing, and controlling the operations of supply chain as efficiently and effectively as possible. SCM involves forecasting, purchasing, inventory management, information management, quality assurance, scheduling, production, distribution, delivery, and customer service (Stevenson, 2007).

Goffin et al. (2006) have stated that supplier management is one of the key issues of SCM because the cost of raw materials and component parts constitute the main cost of a product and most of the firms have to spend considerable amount of their sales revenues on purchasing, hence supplier selection is one of the most important decision making problems. Ghodspour and O'Brien (2001) also agreed that selecting the right supplier significantly reduces the purchasing costs and improves corporate competitiveness. Therefore, appropriate supplier selection improves supply chain performance.

The conventional approach to supplier selection is to contact as many potential suppliers as possible, issue them with procurement specifications, and ask for quotations. In many cases, the offers would be evaluated and purchase order would be issued to the lowest bidder. Increasingly organizations are going for long-term partnership with their suppliers for strategic items so as to get suggestions for new product development and resolving various operational issues. Choosing the right suppliers involves consideration of many quantitative and qualitative factors other than price alone. Several approaches have been proposed for supplier selection, which also consider multiple and conflicting criteria. However, they have not considered the impact of business objectives and requirements of company stakeholders in identifying criteria for supplier selection. Hence, the selected suppliers may not be able to meet the company objectives.

This paper develops an integrated analytical approach for selecting suppliers strategically using a combined QFD and AHP approach. In the approach, multiple evaluating criteria are derived from the requirements of company stakeholders using a series of house of quality (HOQ). The importance of evaluating criteria is prioritized with respect to the degree of achieving the stakeholder requirements using AHP. Based on the ranked criteria, potential suppliers are evaluated using AHP again to make an optimal selection.

2. Literature review

Bhutta (2003) selected and reviewed 154 journal articles on supplier selection and evaluation for the period 1986-2002. The methods used were individual, including total cost approach, multiple attribute utility theory, total cost of ownership (TCO), AHP, data envelopment analysis, and mathematical programming techniques. Among them, TCO was the most prevalent approach, followed by AHP. Because of this finding, Bhutta and Huq (2002) compared TCO and AHP comprehensively. They revealed that AHP can provide a more robust tool for decision makers to select and evaluate suppliers with respect to qualitative and quantitative criteria, instead of cost data only considered in TCO.

Ho et al. (2010) selected and reviewed 70 journal articles on supplier selection and evaluation for the period 2000-2008. Several approaches have been proposed for supplier selection, such as using AHP, analytic network process (ANP), case-based reasoning (CBR), data envelopment analysis (DEA), fuzzy set theory, genetic algorithm (GA), mathematical programming, simple multi-attribute rating technique (SMART), and their integrations. Tables I-II summarize the individual and integrated approaches for supplier selection, respectively.

According to Ho et al. (2010), the most popular individual approach is DEA. DEA has attracted more attention mainly because of its robustness. In the past, it was used to measure the relative efficiencies of homogeneous decision making units (DMUs) based on numerical data only. As the supplier selection problem involves both qualitative and

quantitative criteria, DEA has been modified to handle qualitative data, such as amount of know-how transfer (Saen, 2006), service (Seydel, 2006), supplier reputation (Saen, 2007a), and so on. In addition, it can now be used to consider stochastic performance measures (Talluri et al., 2006), and handle imprecise data (Saen, 2007a; Wu et al., 2007).

There are three limitations or drawbacks of DEA. First, the practitioners may be confused with input and output criteria. For example, some authors considered price/cost as an output criterion (Narasimhan et al., 2001; Talluri and Narasimhan, 2004; Seydel, 2006), whereas the others used it as an input criterion (Liu et al., 2000; Narasimhan et al., 2001; Talluri and Baker, 2002; Talluri and Sarkis, 2002; Talluri and Narasimhan, 2004; Garfamy, 2006; Ross et al., 2006; Saen, 2006; Talluri et al., 2006; Saen, 2007a; Wu et al., 2007). The second problem is due to the subjective assignment of ratings to qualitative criteria. Although Saen (2006) and Seydel (2006) deployed five-point and seven-point scales to rank the priorities of qualitative criteria, respectively, some inconsistencies may be occurred because of subjective judgments. The third concern is due to the nature of DEA. DEA is a linear programming to measure the relative efficiencies of homogenous DMUs. In the other words, those suppliers generating more outputs while requiring less inputs are regarded as the more efficient suppliers. A question is raised "is an efficient supplier equivalent to an effective supplier?"

The second most popular individual approach is AHP, which is a popular multi-criteria decision making technique nowadays. It has been applied to various application areas, including education, engineering, finance, government, industry, management, manufacturing, personal, political, social, and sports in the last 20 years (Steuer and Na, 2003; Vaidya and Kumar, 2006; Ho, 2008). The wide applicability is due to its simplicity, ease of use, and great flexibility. Furthermore, AHP can be used to make a consistent decision with respect to multiple qualitative and quantitative criteria. This is achieved by one of its operations called consistency verification. The operation can help to avoid making inconsistent decisions due to personal or subjective judgments.

Comparatively, the integrated AHP-goal programming approach is more popular than the other integrated approaches. The major reason is that the individual techniques possess unique advantages. As mentioned earlier, the consistency verification operation of AHP contributes greatly to prevent inconsistency because it acts as a feedback mechanism for the decision makers to review and revise their judgments. Consequently, the judgments made are guaranteed to be consistent, which is the basic ingredient for making good decisions. Nevertheless, the output of AHP is the relative importance weightings of criteria and sub-factors merely. In supplier selection problem, besides the weightings of alternative suppliers, the decision makers also need to consider the resource limitations (e.g. budget of buyer and capacities of suppliers). For this reason, the goal programming can compensate for AHP. It can definitely provide more and useful information for the decision makers. Based on the above analysis, it is believed that it must be beneficial to the decision making process if both AHP and goal programming are integrated together.

Although the above mentioned approaches can deal with multiple and conflicting criteria, they have not taken into consideration the impact of business objectives and requirements of company stakeholders on the evaluating criteria. In reality, the weightings of supplier evaluating criteria depend greatly on business priorities and strategies. In cases where the weightings are assigned arbitrarily and subjectively without considering the "voice" of company stakeholders, the suppliers selected may not provide what the company exactly wants.

To better align supplier selection (and sourcing strategy) with corporate/business strategy, an integrated analytical approach, combining QFD and AHP is developed. The most important information that QFD provides is the weights of evaluating criteria, which are derived by the importance ratings of stakeholder requirements together with the relationship weightings between stakeholder requirements and evaluating criterion. Generally, both importance ratings of stakeholder requirements and relationship weightings are determined by the decision makers arbitrarily. This may result in a certain degree of inconsistency, and therefore degrade the quality of decisions made. To overcome this drawback, AHP is used to evaluate them consistently.

Recently, the combined AHP-QFD approach has been applied to many areas, including higher education (Köksal and Eđitman, 1998; Lam and Zhao, 1998), logistics (Chuang, 2001; Partovi, 2006), manufacturing (Wang et al., 1998; Partovi, 1999; Zakarian and Kusiak, 1999; Hsiao, 2002; Kwong and Bai, 2002; Madu et al., 2002; Kwong and Bai, 2003; Myint, 2003; Bhattacharya et al., 2005; Hanumaiah et al., 2006), military (Partovi and Epperly, 1999), and sports (Partovi and Corredoira, 2002). To the best knowledge of the authors, this approach has not yet been applied for supplier selection problem.

3.The proposed supplier selection approach

The proposed supplier selection approach using combined AHP and QFD has been described in the following steps (Figure 1). The approach comprises of series of three houses, including HOQ1 (refer to steps 1 to 5), HOQ2 (refer to steps 6 to 9), and HOQ3 (refer to steps 10 to 13).

Step 1: Identify the company stakeholders, who have a say in the supplier selection process.

Step 2: Determine the importance rating of each stakeholder category.

Step 3: Identify the stakeholder requirements.

Step 4: Determine the relationship weights between the company stakeholders and stakeholder requirements using AHP (steps 4.1 to 4.7).

Step 4.1: AHP pairwise comparison. Construct a pairwise comparison matrix, Equation 1 where n denotes the number of elements (stakeholder requirements in HOQ1), and a_{ij} refers to the comparison of element i to element j with respect to each criterion (company stakeholders in HOQ1). The nine-point scale, shown in Table III, can be used to decide on which element is more important and by how much.

Step 4.2: AHP synthesization. Divide each entry (a_{ij}) in each column of matrix A by its column total. The matrix now becomes a normalized pairwise comparison matrix, Equation 2 where R denotes the set of stakeholder requirements, that is, $R=\{1, 2, \dots, n\}$.

Step 4.3: Compute the average of the entries in each row of matrix A' to yield column vector, Equation 3 where c_{ik} denotes the relationship weightings between stakeholder requirement i and its corresponding stakeholder k in HOQ1.

Step 4.4: AHP consistency verification. Multiply each entry in column i of matrix A by c_{ik} . Then, divide the summation of values in row i by c_{ik} to yield another column vector, Equation 4 where C^- refers to a weighted sum vector.

Step 4.5: Compute the averages of values in vector C^- to yield the maximum eigenvalue of matrix A , Equation 5 .

Step 4.6: Compute the consistency index, Equation 6 .

Step 4.7: Compute the consistency ratio, Equation 7 where $RI(n)$ is a random index of which the value is dependent on the value of n , shown in Table IV. If CR is greater than 0.10, then go to step 4.1. Otherwise, go to step 5.

Step 5: Compute the importance rating of each stakeholder requirement, Equation 8 where S denotes the set of company stakeholders, that is, $S=\{1, 2, \dots, m\}$, and p_k denotes the proportion of stakeholder k .

Step 6: Copy the stakeholder requirements (step 3) and their corresponding importance ratings (step 5) into HOQ2.

Step 7: Identify the supplier evaluating factors.

Step 8: Determine the relationship weightings between evaluating factors i and its corresponding stakeholder requirements k , c_{ik}^2 , using AHP (steps 4.1 to 4.7). Note that, in HOQ2, R denotes the set of evaluating factors, that is, $R=\{1, 2, \dots, n\}$, whereas S denotes the set of stakeholder requirements, that is, $S=\{1, 2, \dots, m\}$.

Step 9: Compute the importance rating of each evaluating factor, Equation 9 where w_k^{-1} is computed in step 5.

Step 10: Copy the evaluating factors (step 7) and their corresponding importance ratings (step 9) into HOQ3.

Step 11: Identify the alternative suppliers.

Step 12: Determine the relationship weightings between suppliers i and its corresponding evaluating factors k , c_{ik}^3 , using AHP (steps 4.1 to 4.7). Note that, in HOQ3, R denotes the set of alternative suppliers, that is, $R=\{1, 2, \dots, n\}$, whereas S denotes the set of evaluating factors, that is, $S=\{1, 2, \dots, m\}$.

Step 13: Finally, calculate the total score of each supplier, Equation 10 where w_k^{-2} is computed in step 9.

4. Application

The proposed strategic sourcing approach is applied to evaluate supplier for a strategic item in a UK-based multinational automobile manufacturing company. The company is a market leader for a few specific brand of cars and successfully completed 60 years of production. It has production facilities in more than 15 countries and has more than four thousands suppliers from more than 70 countries.

The company recently reviewed the performance of its suppliers, including the one being collaborated with (S1) and three other potential suppliers (S2, S3, and S4). The aim of this review was to determine supplier performance in terms of the ability of satisfying the company's requirements.

The following paragraphs demonstrate the application of proposed approach using step-by-step approach.

Step 1: Identify the company stakeholders

To evaluate and select the best supplier, the company stakeholders who have a say in supplier selection were identified first. In this case, there were four categories or departments: finance, procurement, production, and quality control.

Step 2: Determine the importance rating of each stakeholder category

The importance rating of each stakeholder category needs to be determined by the company's management team using AHP. A stakeholder with a higher importance rating means that s/he has more impact on the selection process. Summation of the importance ratings is equal to one.

Step 3: Identify the stakeholder requirements

In the third step, the stakeholder requirements were identified through a brainstorming session among the identified stakeholders. The brainstorming session resulted nine stakeholder requirements. They are shown in Table V.

Step 4: Determine the relationship weights between the company stakeholders and stakeholder requirements using AHP

To calculate the importance of stakeholder requirements, the relationship weights between the stakeholders and their requirements were determined using AHP. For example, the procedure of calculating the relationship weights for finance department is to construct a pairwise comparison matrix first as shown in Figure 2. Because four requirements were related to the finance department, there were four elements in matrix A only. The relevant requirements were "EDI", "Established business and financial stability", "Reference from satisfied customers", and "Total cost ownership". For synthesization, a normalized comparison matrix is constructed as shown in Figure 3. Based on matrix A' , a column vector showing the relationship weightings between stakeholder requirements and finance department was constructed as shown in Figure 4. To verify the consistency, a weighted sum vector was

constructed as shown in Figure 5. Then, the maximum eigenvalue of matrix A, consistency index, and consistency ratio were computed as follows. Equation 11 Equation 12 Equation 13 Because CR was less than 0.10, the pairwise comparison for the finance department was consistent.

Step 5: Compute the importance rating of each stakeholder requirement

Following the above procedure for determining the relationship weights between the stakeholder requirements and the remaining stakeholders, the importance ratings of each stakeholder requirement were computed in HOQ1 as shown in Table VI.

Step 6: Copy the stakeholder requirements (step 3) and their corresponding importance ratings (step 5) into HOQ2

After completing HOQ1, both stakeholder requirements and their corresponding importance ratings were copied into HOQ2, which linked the requirements and evaluating factors.

Step 7: Identify the supplier evaluating factors

In this HOQ, stakeholder requirements were regarded as “what's”, whereas evaluating factors were akin to “how's”. The evaluating factors were proposed by the stakeholders according to the results of a questionnaire. In this case, there were 20 evaluating factors that the supplier should possess in order to achieve the stakeholder requirements. Table VII shows the list of evaluating criteria and their sub-factors.

Step 8: Determine the relationship weights between evaluating factors and its corresponding stakeholder requirements

Similar to HOQ1, AHP was used to calculate the relationship weightings between the stakeholder requirements and evaluating factors in HOQ2. Certainly, the size of each pairwise comparison matrix was varied, and was dependent on the number of evaluating factors that will achieve a particular requirement. For example, there were five elements in the matrix for the requirement “Compliance with industrial standards and procedures”. They were “Approved packaging”, “Product audits”, “Highest quality standards”, “Zero defect attitude” and “Quality and productivity improvement”. All of them were related to the requirement.

Step 9: Compute the importance rating of each evaluating factor

After determining all relationship weightings between the nine stakeholder requirements and their related evaluating factors, the importance ratings of each factor were computed in HOQ2 as shown in Tables VIII–IX. According to HOQ2, the five most critical factors were “Highest quality standards”, “Quality and productivity improvement”, “Sustainable low cost through”, “Zero defects attitude”, and “100 percent on time delivery”. The finding was almost identical to that in Ho et al. (2010), which revealed that “Quality”, “Delivery”, and “Cost” were the most important evaluating factors.

Step 10: Copy the evaluating factors (step 7) and their corresponding importance ratings (step 9) into HOQ3

In the last stage, both evaluating factors and their corresponding importance ratings were copied into HOQ3, which evaluates the suppliers with respect to the 20 evaluating factors.

Step 11: Identify the alternative suppliers

As mentioned earlier, there were four supplier alternatives to be evaluated, including one being currently collaborated with and three other candidate suppliers.

Step 12: Determine the relationship weightings between suppliers i and its corresponding evaluating factors

AHP was used again to calculate the relationship weightings between the evaluating factors and suppliers in HOQ3.

Step 13: Finally, calculate the total score of each supplier

After determining all relationship weights, the importance ratings of each supplier were computed in HOQ3 as shown in Table X. According to HOQ3, the performance of the third supplier was the best, followed by S2, S1, and S4. Alternatively, the performance of suppliers can be evaluated with respect to some critical factors instead of all 20 factors. Based on the five critical factors mentioned in step 9, the performance of S3 was the best (0.204), followed by S1 (0.118), S2 (0.102), and S4 (0.067). According to both evaluations, the company should terminate the collaboration with the current supplier, and replace S1 by S3.

5. Result analysis

In this section, we focus on comparing alternative suppliers with respect to the six evaluating criteria – cost, delivery, quality, management, technology, and relationship. The factors of each criterion will be analyzed to understand why S3 outperforms the others, and examine how the supplier replacement will be beneficial to the automobile manufacturing company.

The first criterion is “cost”, in which there are four factors as shown in Table XI. S3 gets the highest score because it has the highest degree of cost transparency, it is the most active supplier in terms of cost reduction, and most important, most of its raw materials are the cheapest. In the financial perspective, collaborating with S3 will help to minimize the expenses.

The comparison of alternative suppliers with respect to “delivery” is shown in Table XII. Because of having a large fleet size, S3 has a better performance in terms of on time delivery. Besides, it is the second best supplier in terms of secured and safety packaging. Fast and reliable delivery is utmost important in contemporary supply chain management because this ensures that right amount of incoming raw materials is available at the right time.

The comparison of alternative suppliers with respect to “quality” is shown in Table XIII. S3 gets the highest score because it focuses on product audits most, various quality standards, such as statistical process control, are applied to monitor the production processes (i.e. “Highest quality standards”), and its ability of continuously improving quality and productivity is the highest (i.e. “Quality and productivity improvement”). However, its' staff awareness of achieving zero defect is not as high as S1 (i.e. “Zero defect attitude”). In summary, collaborating with S3 will help to increase the quality of automobiles, and reduce the cost of poor quality, especially the internal failure costs due to defective incoming raw materials.

According to Table XIV, S3 scores the highest in all factors of “management” criterion. Instead of supplying standardized raw materials, S3 is able to adjust the production lines to manufacture various types of raw materials based on buyers' requests (i.e. Flexibility in change adaptation). S3 is able to increase its internal capacity and acquire external capacity from sub-contractors to adapt to unpredictable high demand (i.e. Capacity management). In addition, S3 is financially sound and credit worthy (i.e. Good financial circumstance; Evidence of tax payments and insurance). Collaborating with such a flexible and reliable supplier will help to reduce risks and uncertainties faced by the automobile manufacturing company.

The comparison of alternative suppliers with respect to “technology” is shown in Table XV. S3 possesses comprehensive information systems, including EDI and extranet, for its buyers to place orders online. This will help to shorten the order cycle, and reduce the cost of placing orders manually. Besides, workforces in S3 have high technical and innovation skills. It invests on research and development heavily, and this helps to increase the uniqueness of raw materials supplied.

Finally, the comparison of alternative suppliers with respect to “relationship” is shown in Table XVI. Again, S3 gets the highest score because it treats its buyers favorably (i.e. Preferred customer treatment) by providing various value-added services (e.g. track-and-trace system and free technical support). Moreover, S3 has the highest degree of strategy transparency. Its missions and visions are shown explicitly on the company website.

Based on the above analysis, there are numerous advantages of terminating the collaboration with the current supplier, and replacing S1 by S3. In summary, this supplier replacement will help to enhance the competitiveness of automobile manufacturing company by reducing costs, increasing quality, speed, flexibility, and value. These are the five dimensions that an organization must possess in order to differentiate itself from the competitors. Evaluating suppliers with respect to cost factors using the traditional approaches, such as TCO and mathematical programming, cannot guarantee that the selected supplier is optimal in contemporary supply chain management because multiple criteria should be considered, as the proposed approach did.

6. Conclusions

This paper develops a combined QFD and AHP approach to measure the performance of alternative suppliers. The effectiveness of approach has been demonstrated using a case study of UK-based automobile manufacturing company. In the approach, QFD has been used to translate the company stakeholder requirements into multiple evaluating factors for supplier selection, which are used to benchmark the suppliers. AHP was used to determine the importance of evaluating factors and preference of each supplier with respect to each selection criterion.

There are many advantages of this integrated approach. First, multiple qualitative and quantitative factors can be considered to evaluate the performance of alternative suppliers. This will ensure that the selected supplier is optimal in terms of lowest cost, highest quality, fastest delivery, greatest flexibility, and highest value-added. Second, the evaluating factors are related to the strategic intent of company through the involvement of concerned stakeholders. This ensures successful strategic sourcing because the supplier selected can achieve the business objectives. Third, the application of AHP ensures consistent supplier performance measurement using benchmarking approach. This ensures that the judgments made are guaranteed to be consistent, which is the basic ingredient for making good decisions. Fourth, the integrated approach involves a team of people representing various functional departments (finance, procurement, production, and quality control) for supplier selection. The active involvement of these departments can lead to a balanced consideration of the requirements or “what’s” at each stage of this translation process, and provide a mechanism to communicate hidden knowledge - knowledge that is known by one individual or department but may not otherwise be communicated through the organization. This methodology helps procurement personnel understand the essential requirements from various departments. Besides internal stakeholders, this integrated approach can also take external stakeholders, such as customers, publics, and government, into consideration. Based on the requirements of various relevant stakeholders, the sourcing decisions can be made more strategically and effectively. Fifth, sensitivity analysis utility of AHP could be applied here in order to check the effect of changes in the importance levels of various factors on final outcome. Therefore, the proposed approach outranks the conventional approaches to supplier selection and supplier performance measurement.

The major limitation or drawback of proposed integrated approach is due to AHP. It may be time-consuming in reaching consensus. Decision makers have to compare each cluster in the same level in a pairwise fashion based on their own experience and knowledge. For instance, every two criteria in the second level are compared at each time with respect to the goal, whereas every two sub-factors of the same criteria in the third level are compared at a time with respect to the corresponding criterion. If it is found that the consistency ratio exceeds the limit, the decision makers have to review and revise the pairwise comparisons again.

Similar approach could be principally adopted in other decision-making scenarios for effective management of supply chain, including third-party logistics service provider evaluation and selection, distribution center and warehouse location evaluation and selection, supply chain performance measurement, and so on. However, this calls for thorough research as both frameworks and criteria for decision-making are likely to vary widely depending on the context.

Equation 1

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix},$$

Equation 2

$$A' = \begin{bmatrix} \sum_{i \in R} \frac{a_{11}}{a_{i1}} & \sum_{i \in R} \frac{a_{12}}{a_{i2}} & \cdots & \sum_{i \in R} \frac{a_{1n}}{a_{in}} \\ \sum_{i \in R} \frac{a_{21}}{a_{i1}} & \sum_{i \in R} \frac{a_{22}}{a_{i2}} & \cdots & \sum_{i \in R} \frac{a_{2n}}{a_{in}} \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{i \in R} \frac{a_{n1}}{a_{i1}} & \sum_{i \in R} \frac{a_{n2}}{a_{i2}} & \cdots & \sum_{i \in R} \frac{a_{nn}}{a_{in}} \end{bmatrix},$$

Equation 3

$$C = \begin{bmatrix} c_{1k}^1 \\ \vdots \\ c_{nk}^1 \end{bmatrix} = \begin{bmatrix} \left(\frac{\sum_{i \in R} \frac{a_{11}}{a_{i1}} + \sum_{i \in R} \frac{a_{12}}{a_{i2}} + \cdots + \sum_{i \in R} \frac{a_{1n}}{a_{in}}}{n} \right) \\ \vdots \\ \left(\frac{\sum_{i \in R} \frac{a_{n1}}{a_{i1}} + \sum_{i \in R} \frac{a_{n2}}{a_{i2}} + \cdots + \sum_{i \in R} \frac{a_{nn}}{a_{in}}}{n} \right) \end{bmatrix}$$

Equation 4

$$\bar{C} = \begin{bmatrix} \bar{c}_{1k}^1 \\ \vdots \\ \bar{c}_{nk}^1 \end{bmatrix} = \begin{bmatrix} \frac{c_{1k}^1 a_{11} + c_{2k}^1 a_{12} + \cdots + c_{nk}^1 a_{1n}}{c_{1k}^1} \\ \vdots \\ \frac{c_{1k}^1 a_{n1} + c_{2k}^1 a_{n2} + \cdots + c_{nk}^1 a_{nn}}{c_{nk}^1} \end{bmatrix},$$

Equation 5

$$\lambda_{\max} = \frac{\sum_{i \in R} \bar{c}_{ik}^1}{n}$$

Equation 6

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

Equation 7

$$CR = \frac{CI}{RI(n)}$$

Equation 8

$$w_i^1 = \sum_{k \in S} p_k c_{ik}^1$$

Equation 9

$$w_i^2 = \sum_{k \in S} \bar{w}_k^1 c_{ik}^2$$

Equation 10

$$w_i^3 = \sum_{k \in S} \bar{w}_k^2 c_{ik}^3$$

Equation 11

$$\lambda_{\max} = \frac{4.015 + 4.042 + 4.016 + 4.051}{4} = 4.031$$

Equation 12

$$CI = \frac{4.031 - 4}{4 - 1} = 0.010$$

Equation 13

$$CR = \frac{0.010}{0.90} = 0.011$$

Figure 1 Proposed methodology for supplier selection

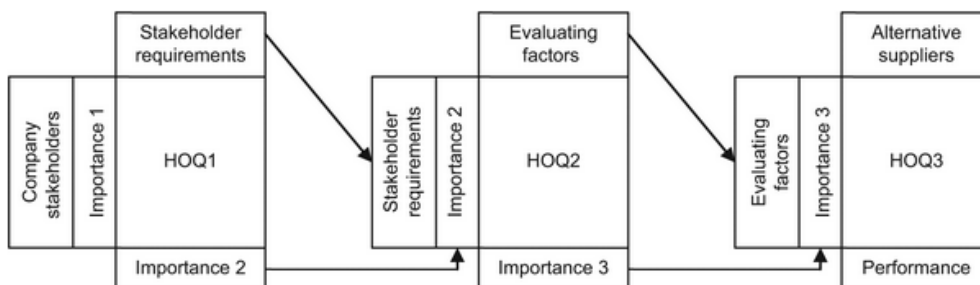


Figure 2 Pairwise comparison matrix

$$A = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{2} & \frac{1}{4} \\ 3 & 1 & 2 & \frac{1}{2} \\ 2 & \frac{1}{2} & 1 & \frac{1}{3} \\ 4 & 2 & 3 & 1 \end{bmatrix}$$

Figure 3 Normalized pairwise comparison matrix

$$A' = \begin{bmatrix} 0.100 & 0.087 & 0.077 & 0.120 \\ 0.300 & 0.261 & 0.308 & 0.240 \\ 0.200 & 0.130 & 0.154 & 0.160 \\ 0.400 & 0.522 & 0.462 & 0.480 \end{bmatrix}$$

Figure 4 Column vector

$$C = \begin{bmatrix} 0.096 \\ 0.277 \\ 0.161 \\ 0.466 \end{bmatrix}$$

Figure 5 Weighted sum vector

$$\bar{C} = \begin{bmatrix} 4.015 \\ 4.042 \\ 4.016 \\ 4.051 \end{bmatrix}$$

[UNAVAILABLE IN THIS VERSION]:

Table I Summary of individual approaches for supplier selection

Table II Summary of integrated approaches for supplier selection

Table III AHP pairwise comparison scale

Table IV List of random index values

Table V Descriptions of company stakeholder requirements

Table VI HOQ1 – linking company stakeholders and their requirements

Table VII A list of supplier evaluating criteria

Table VIII HOQ2 – linking stakeholder requirements and evaluating factors

Table IX HOQ2 – linking stakeholder requirements and evaluating factors

Table XHOQ3 – linking evaluating factors and alternative suppliers

Table XIA comparison of the alternative suppliers with respect to cost

Table XIIA comparison of the alternative suppliers with respect to delivery

Table XIIIA comparison of the alternative suppliers with respect to quality

Table XIVA comparison of the alternative suppliers with respect to management

Table XVA comparison of the alternative suppliers with respect to technology

Table X VIA comparison of the alternative suppliers with respect to relationship

References

- Akarte, M.M., Surendra, N.V., Ravi, B., Rangaraj, N. (2001), "Web based casting supplier evaluation using analytical hierarchy process", *Journal of the Operational Research Society*, Vol. 52 pp.511-22.
- Amid, A., Ghodsypour, S.H., O'Brien, C. (2006), "Fuzzy multiobjective linear model for supplier selection in a supply chain", *International Journal of Production Economics*, Vol. 104 pp.394-407.
- Amid, A., Ghodsypour, S.H., O'Brien, C. (2009), "A weighted additive fuzzy multiobjective model for the supplier selection problem under price breaks in a supply chain", *International Journal of Production Economics*, Vol. 121 No.2, pp.323-32.
- Barla, S.B. (2003), "A case study of supplier selection for lean supply by using a mathematical model", *Logistics Information Management*, Vol. 16 No.6, pp.451-9.
- Bayazit, O. (2006), "Use of analytic network process in vendor selection decisions", *Benchmarking: An International Journal*, Vol. 13 No.5, pp.566-79.
- Bevilacqua, M., Ciarapica, F.E., Giacchetta, G. (2006), "A fuzzy-QFD approach to supplier selection", *Journal of Purchasing & Supply Management*, Vol. 12 pp.14-27.
- Bhattacharya, A., Sarkar, B., Mukherjee, S.K. (2005), "Integrating AHP with QFD for robot selection under requirement perspective", *International Journal of Production Research*, Vol. 43 No.17, pp.3671-85.
- Bhutta, K. (2003), "Supplier selection problem: methodology literature review", *Journal of International Technology and Information Management*, Vol. 12 No.2, pp.53-71.
- Bhutta, K., Huq, F. (2002), "Supplier selection problem: a comparison of the total cost of ownership and analytic hierarchy process approaches", *Supply Chain Management: An International Journal*, Vol. 7 No.3, pp.126-35.
- Bottani, E., Rizzi, A. (2008), "An adapted multi-criteria approach to suppliers and products selection – an application oriented to lead-time reduction", *International Journal Production Economics*, Vol. 111 pp.763-81.
- Braglia, M., Petroni, A. (2000), "A quality assurance-oriented methodology for handling trade-offs in supplier selection", *International Journal of Physical Distribution & Logistics Management*, Vol. 30 No.2, pp.96-111.
- Çebi, F., Bayraktar, D. (2003), "An integrated approach for supplier selection", *Logistics Information Management*, Vol. 16 No.6, pp.395-400.
- Chan, F.T.S. (2003), "Interactive selection model for supplier selection process: an analytical hierarchy process approach", *International Journal Production Research*, Vol. 41 No.15, pp.3549-79.
- Chan, F.T.S., Chan, H.K. (2004), "Development of the supplier selection model – a case study in the advanced technology industry", *Proceedings of the Institution of Mechanical Engineers Part B, Journal of Engineering Manufacture*, Vol. 218 pp.1807-24.
- Chan, F.T.S., Kumar, N. (2007), "Global supplier development considering risk factors using fuzzy extended AHP-based approach", *OMEGA – International Journal of Management Science*, Vol. 35 pp.417-31.
- Chan, F.T.S., Chan, H.K., Ip, R.W.L., Lau, H.C.W. (2007), "A decision support system for supplier selection in the airline industry", *Proceedings of the Institution of Mechanical Engineers Part B, Journal of Engineering Manufacture*, Vol. 221 pp.741-58.

- Chen, C.T., Lin, C.T., Huang, S.F. (2006), "A fuzzy approach for supplier evaluation and selection in supply chain management", *International Journal of Production Economics*, Vol. 102 pp.289-301.
- Chen, Y.M., Huang, P.N. (2007), "Bi-negotiation integrated AHP in suppliers selection", *Benchmarking: An International Journal*, Vol. 14 No.5, pp.575-93.
- Chou, S.Y., Chang, Y.H. (2008), "A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach", *Expert Systems with Applications*, Vol. 34 pp.2241-53.
- Choy, K.L., Lee, W.B. (2002), "A generic tool for the selection and management of supplier relationships in an outsourced manufacturing environment: the application of case based reasoning", *Logistics Information Management*, Vol. 15 No.4, pp.235-53.
- Choy, K.L., Lee, W.B. (2003), "A generic supplier management tool for outsourcing manufacturing", *Supply Chain Management: An International Journal*, Vol. 8 No.2, pp.140-54.
- Choy, K.L., Fan, K.K.H., Lo, V. (2003a), "Development of an intelligent customer-supplier relationship management system: the application of case-based reasoning", *Industrial Management & Data Systems*, Vol. 103 No.4, pp.263-74.
- Choy, K.L., Lee, W.B., Lo, V. (2002), "Development of a case based intelligent customer – supplier relationship management system", *Expert Systems with Applications*, Vol. 23 pp.281-97.
- Choy, K.L., Lee, W.B., Lo, V. (2003b), "Design of a case based intelligent supplier relationship management system – the integration of supplier rating system and product coding system", *Expert Systems with Applications*, Vol. 25 pp.87-100.
- Choy, K.L., Lee, W.B., Lo, V. (2003c), "Design of an intelligent supplier relationship management system: a hybrid case based neural network approach", *Expert Systems with Applications*, Vol. 24 pp.225-37.
- Choy, K.L., Lee, W.B., Lo, V. (2004a), "An enterprise collaborative management system – a case study of supplier relationship management", *The Journal of Enterprise Information Management*, Vol. 17 No.3, pp.191-207.
- Choy, K.L., Lee, W.B., Lo, V. (2005), "A knowledge-based supplier intelligence retrieval system for outsource manufacturing", *Knowledge-based systems*, Vol. 18 pp.1-17.
- Choy, K.L., Lee, W.B., Lau, H.C.W., Lu, D., Lo, V. (2004b), "Design of an intelligent supplier relationship management system for new product development", *International Journal of Computer Integrated Manufacturing*, Vol. 17 No.8, pp.692-715.
- Chuang, P.T. (2001), "Combining the analytic hierarchy process and quality function deployment for a location decision from a requirement perspective", *International Journal of Advanced Manufacturing Technology*, Vol. 18 No.11, pp.842-9.
- Demirtas, E.A., Üstün, Ö. (2008), "An integrated multi-objective decision making process for supplier selection and order allocation", *OMEGA – International Journal of Management Science*, Vol. 36 pp.76-90.
- Demirtas, E.A., Üstün, Ö. (2009), "Analytic network process and multi-period goal programming integration in purchasing decisions", *Computer and Industrial Engineering*, Vol. 56 No.2, pp.677-90.
- Ding, H., Benyoucef, L., Xie, X. (2005), "A simulation optimization methodology for supplier selection problem", *International Journal Computer Integrated Manufacturing*, Vol. 18 No.2-3, pp.210-24.
- Florez-Lopez, R. (2007), "Strategic supplier selection in the added-value perspective: a CI approach", *Information Sciences*, Vol. 177 pp.1169-79.
- Forker, L.B., Mendez, D. (2001), "An analytical method for benchmarking best peer suppliers", *International Journal of Operations and Production Management*, Vol. 21 No.1-2, pp.195-209.
- Garfamy, R.M. (2006), "A data envelopment analysis approach based on total cost of ownership for supplier selection", *Journal of Enterprise Information Management*, Vol. 19 No.6, pp.662-78.
- Gencer, C., Gürpınar, D. (2007), "Analytic network process in supplier selection: a case study in an electronic firm", *Applied Mathematical Modeling*, Vol. 31 pp.2475-86.
- Ghodsypour, S.H., O'Brien, C. (2001), "The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint", *International Journal of Production Economics*, Vol. 73 No.1, pp.15-27.

- Goffin, K., Lemke, F., Szejcowski, M. (2006), "An exploratory study of 'close' supplier-manufacturer relationships", *Journal of Operations Management*, Vol. 24 No.2, pp.189-209.
- Ha, S.H., Krishnan, R. (2008), "A hybrid approach to supplier selection for the maintenance of a competitive supply chain", *Expert Systems with Applications*, Vol. 34 pp.1303-11.
- Hanumaiah, N., Ravi, B., Mukherjee, N.P. (2006), "Rapid hard tooling process selection using QFD-AHP methodology", *Journal of Manufacturing Technology Management*, Vol. 17 No.3, pp.332-50.
- Ho, W. (2008), "Integrated analytic hierarchy process and its applications – a literature review", *European Journal of Operational Research*, Vol. 186 pp.211-28.
- Ho, W., Xu, X., Dey, P. (2010), "Multi-criteria decision making approaches for supplier evaluation and selection: a literature review", *European Journal of Operational Research*, Vol. 202 No.1, pp.16-24.
- Hong, G.H., Park, S.C., Jang, D.S., Rho, H.M. (2005), "An effective supplier selection method for constructing a competitive supply-relationship", *Expert Systems with Applications*, Vol. 28 pp.629-39.
- Hou, J., Su, D. (2007), "EJB-MVC oriented supplier selection system for mass customization", *Journal of Manufacturing Technology Management*, Vol. 18 No.1, pp.54-71.
- Hsiao, S.W. (2002), "Concurrent design method for developing a new product", *International Journal of Industrial Ergonomics*, Vol. 29 No.1, pp.41-55.
- Huang, S.H., Keska, H. (2007), "Comprehensive and configurable metrics for supplier selection", *International Journal of Production Economics*, Vol. 105 pp.510-23.
- Jain, V., Tiwari, M.K., Chan, F.T.S. (2004), "Evaluation of the supplier performance using an evolutionary fuzzy-based approach", *Journal of Manufacturing Technology Management*, Vol. 15 No.8, pp.735-44.
- Kahraman, C., Cebeci, U., Ulukan, Z. (2003), "Multi-criteria supplier selection using fuzzy AHP", *Logistics Information Management*, Vol. 16 No.6, pp.382-94.
- Karpak, B., Kumcu, E., Kasuganti, R.R. (2001), "Purchasing materials in the supply chain: managing a multi-objective task", *European Journal of Purchasing & Supply Management*, Vol. 7 pp.209-16.
- Köksal, G., Eđitman, A. (1998), "Planning and design of industrial engineering education quality", *Computers & Industrial Engineering*, Vol. 35 No.3-4, pp.639-42.
- Kwong, C.K., Bai, H. (2002), "A fuzzy AHP approach to the determination of importance weights of customer requirements in quality function deployment", *Journal of Intelligent Manufacturing*, Vol. 13 No.5, pp.367-77.
- Kwong, C.K., Bai, H. (2003), "Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach", *IIE Transactions*, Vol. 35 No.7, pp.619-26.
- Kwong, C.K., Ip, W.H., Chan, J.W.K. (2002), "Combining scoring method and fuzzy expert systems approach to supplier assessment: a case study", *Integrated Manufacturing Systems*, Vol. 13 No.7, pp.512-9.
- Lam, K., Zhao, X. (1998), "An application of quality function deployment to improve the quality of teaching", *International Journal of Quality & Reliability Management*, Vol. 15 No.4, pp.389-413.
- Lau, H.C.W., Lee, C.K.M., Ho, G.T.S., Pun, K.F., Choy, K.L. (2006), "A performance benchmarking system to support supplier selection", *International Journal of Business Performance Management*, Vol. 8 No.2-3, pp.132-51.
- Liao, Z., Rittscher, J. (2007), "A multi-objective supplier selection model under stochastic demand conditions", *International Journal of Production Economics*, Vol. 105 pp.150-9.
- Liu, F.H.F., Hai, H.L. (2005), "The voting analytic hierarchy process method for selecting supplier", *International Journal of Production Economics*, Vol. 97 pp.308-17.
- Liu, J., Ding, F.Y., Lall, V. (2000), "Using data envelopment analysis to compare suppliers for supplier selection and performance improvement", *Supply Chain Management: An International Journal*, Vol. 5 No.3, pp.143-50.

- Madu, C.N., Kuei, C., Madu, I.E. (2002), "A hierarchic metric approach for integration of green issues in manufacturing: a paper recycling application", *Journal of Environmental Management*, Vol. 64 No.3, pp.261-72.
- Muralidharan, C., Anantharaman, N., Deshmukh, S.G. (2002), "A multi-criteria group decision-making model for supplier rating", *Journal of Supply Chain Management*, Vol. 38 No.4, pp.22-33.
- Myint, S. (2003), "A framework of an intelligent quality function deployment (IQFD) for discrete assembly environment", *Computers & Industrial Engineering*, Vol. 45 No.2, pp.269-83.
- Narasimhan, R., Talluri, S., Mahapatra, S.K. (2006), "Multiproduct, multicriteria model for supplier selection with product life-cycle considerations", *Decision Sciences*, Vol. 37 No.4, pp.577-603.
- Narasimhan, R., Talluri, S., Mendez, D. (2001), "Supplier evaluation and rationalization via data envelopment analysis: an empirical examination", *Journal of Supply Chain Management*, Vol. 37 No.3, pp.28-37.
- Ng, W.L. (2008), "An efficient and simple model for multiple criteria supplier selection problem", *European Journal of Operational Research*, Vol. 186 pp.1059-67.
- Partovi, F.Y. (1999), "A quality function deployment approach to strategic capital budgeting", *The Engineering Economist*, Vol. 44 No.3, pp.239-60.
- Partovi, F.Y. (2006), "An analytic model for locating facilities strategically", *Omega*, Vol. 34 No.1, pp.41-55.
- Partovi, F.Y., Corredoira, R.A. (2002), "Quality function deployment for the good of soccer", *European Journal of Operational Research*, Vol. 137 No.3, pp.642-56.
- Partovi, F.Y., Epperly, J.M. (1999), "A quality function deployment approach to task organization in peacekeeping force design", *Socio-Economic Planning Sciences*, Vol. 33 No.2, pp.131-49.
- Perçin, S. (2006), "An application of the integrated AHP-PGP model in supplier selection", *Measuring Business Excellence*, Vol. 10 No.4, pp.34-49.
- Ramanathan, R. (2007), "Supplier selection problem: integrating DEA with the approaches of total cost of ownership and AHP", *Supply Chain Management: An International Journal*, Vol. 12 No.4, pp.258-61.
- Ross, A., Buffa, F.P., Dröge, C., Carrington, D. (2006), "Supplier evaluation in a dyadic relationship: an action research approach", *Journal of Business Logistics*, Vol. 27 No.2, pp.75-102.
- Saen, R.F. (2006), "A decision model for selecting technology suppliers in the presence of nondiscretionary factors", *Applied Mathematics and Computation*, Vol. 181 pp.1609-15.
- Saen, R.F. (2007a), "Suppliers selection in the presence of both cardinal and ordinal data", *European Journal of Operational Research*, Vol. 183 pp.741-7.
- Saen, R.F. (2007b), "A new mathematical approach for supplier selection: accounting for non-homogeneity is important", *Applied Mathematics and Computation*, Vol. 185 pp.84-95.
- Sarkar, A., Mohapatra, P.K.J. (2006), "Evaluation of supplier capability and performance: a method for supply base reduction", *Journal of Purchasing & Supply Management*, Vol. 12 pp.148-63.
- Sarkis, J., Talluri, S. (2002), "A model for strategic supplier selection", *Journal of Supply Chain Management*, Vol. 38 No.1, pp.18-28.
- Sevklı, M., Koh, S.C.L., Zaim, S., Demirbag, M., Tatoglu, E. (2007), "An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey", *International Journal of Production Research*, Vol. 45 No.9, pp.1973-2003.
- Seydel, J. (2005), "Supporting the paradigm shift in vendor selection: multicriteria methods for sole-sourcing", *Managerial Finance*, Vol. 31 No.3, pp.49-66.
- Seydel, J. (2006), "Data envelopment analysis for decision support", *Industrial Management & Data Systems*, Vol. 106 No.1, pp.81-95.
- Steuer, R.E., Na, P. (2003), "Multiple criteria decision making combined with finance: a categorized bibliographic study", *European Journal of Operational Research*, Vol. 150 No.3, pp.496-515.
- Stevenson, W.J. (2007), *Operations Management*, 9th ed., McGraw-Hill, Maidenhead, .

- Talluri, S., Baker, R.C. (2002), "A multi-phase mathematical programming approach for effective supply chain design", *European Journal of Operational Research*, Vol. 141 pp.544-58.
- Talluri, S., Narasimhan, R. (2004), "A methodology for strategic sourcing", *European Journal of Operational Research*, Vol. 154 pp.236-50.
- Talluri, S., Sarkis, J. (2002), "A model for performance monitoring of suppliers", *International Journal of Production Research*, Vol. 40 No.16, pp.4257-69.
- Talluri, S., Narasimhan, R., Nair, A. (2006), "Vendor performance with supply risk: a chance-constrained DEA approach", *International Journal of Production Economics*, Vol. 100 pp.212-22.
- Vaidya, O.S., Kumar, S. (2006), "Analytic hierarchy process: an overview of applications", *European Journal of Operational Research*, Vol. 169 No.1, pp.1-29.
- Wang, G., Huang, S.H., Dismukes, J.P. (2004), "Product-driven supply chain selection using integrated multi-criteria decision-making methodology", *International Journal of Production Economics*, Vol. 91 pp.1-15.
- Wang, G., Huang, S.H., Dismukes, J.P. (2005), "Manufacturing supply chain design and evaluation", *International Journal of Advanced Manufacturing Technology*, Vol. 25 pp.93-100.
- Wang, H., Xie, M., Goh, T.N. (1998), "A comparative study of the prioritization matrix method and the analytic hierarchy process technique in quality function deployment", *Total Quality Management*, Vol. 9 No.6, pp.421-30.
- Weber, C.A., Current, J., Desai, A. (2000), "An optimization approach to determining the number of vendors to employ", *Supply Chain Management: An International Journal*, Vol. 5 No.2, pp.90-8.
- Wu, T., Shunk, D., Blackhurst, J., Appalla, R. (2007), "AIDEA: a methodology for supplier evaluation and selection in a supplier-based manufacturing environment", *International Journal of Manufacturing Technology and Management*, Vol. 11 No.2, pp.174-92.
- Xia, W., Wu, Z. (2007), "Supplier selection with multiple criteria in volume discount environments", *OMEGA – International Journal of Management Science*, Vol. 35 pp.494-504.
- Yang, C.C., Chen, B.S. (2006), "Supplier selection using combined analytical hierarchy process and grey relational analysis", *Journal of Manufacturing Technology Management*, Vol. 17 No.7, pp.926-41.
- Zakarian, A., Kusiak, A. (1999), "Forming teams: an analytic approach", *IIE Transactions*, Vol. 31 No.1, pp.85-97.