Expert Systems with Applications 38 (2011) 2741–2751

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A combined methodology for supplier selection and performance evaluation

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ARTICLE INFO

Keywords:
Supplier evaluation
Multi-criteria decision making techniques
Performance improvement

ABSTRACT

Today, organizations that wish to carry on the sustainable growing need a robust strategic performance measurement and evaluation system because of changing demands of consumers, reduced product life cycle, competitive and globalised markets. In this study, a new methodology is introduced and proposed for increasing the supplier selection and evaluation quality. The new approach considers both qualitative and quantitative variables in evaluating performance for selection of suppliers based on efficiency and effectiveness in one of the biggest car manufacturing factory in Turkey. This new methodology is realized in two steps. In the first stage, qualitative performance evaluation is performed by using fuzzy AHP (Analytical Hierarchical Process) in finding criteria weights and then fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is utilized in finding the ranking of suppliers. So, qualitative variables are transformed into a quantitative variable for using in DEA (Data Envelopment Analysis) methodology as an output called quality management system audit. In the second stage, DEA is performed with one dummy input and four output variables, namely, quality management system audit, warranty cost ratio, defect ratio, quality management. As a result, comparing with the present system applied by the car factory, the new method seems to be some advantages and superiorities for making the decision in buying the quality car luggage side part (panel) by selecting the suitable supplier(s) in an automotive factory of Turkey.

1. Introduction

To choose the right supplier deals, with an important evaluation, and selection problems in the purchasing function of a business. A good supplier selection makes a significant difference to an organization's future to reduce operational costs and improve the quality of its end products. There have been a lot of factors in today's global market in which that influence companies to search for a competitive advantage by focusing on purchasing raw materials and component parts represents the largest percentage of the total product cost. For instance, high technology products such as motor vehicles, railroad&transport equipment, machinery&equipment components, purchased materials and services account for up to 80% of the total product cost. Therefore, selecting the right suppliers is a key to the procurement process and represents a major opportunity for companies to reduce costs. On the other hand, selecting the wrong suppliers can cause operational and financial problems (Weber, Current, & Benton, 1991). The traditional approach to supplier selection has been to select suppliers solely on the basis of price for many years. However, as companies have learned that price as a single criterion for supplier selection is insufficient, they have turned into more comprehensive multi-criteria decision making techniques. Recently, these criteria have become increasingly complex as environmental, social, political, and customer satisfaction concerns have been added to the traditional factors of quality, delivery, cost, and service. Apart from cost reduction, companies continuously work with suppliers to remain competitive by reducing product development time, improving product quality, and reducing lead times. For instance, a qualified base of suppliers helps a company achieve greater innovation through improved product design and increased flexibility. Some authors have identified several criteria for supplier selection, such as the net price, quality, delivery, historical supplier performance, capacity, communication systems, service, and geographic location, among others (Dempsey, 1978). These evaluation criteria involve trade-offs and are a key issue in the supplier assessment process since it measures the performance of suppliers. For example, one vendor may offer inexpensive parts of slightly below average quality, while another vendor may offer higher quality parts, with uncertain delivery thus setting up trade-offs. In addition, the importance of each criterion, varies from one purchase to the next and is complicated further by the fact that some criteria are quantitative (price, quality, etc.), while others are qualitative (service, flexibility, etc.). Thus, a technique is needed that can adjust for the decision maker's attitude toward the importance of each criterion

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0957-4174/$ - see front matter
doi:10.1016/j.eswa.2010.08.064

and incorporates both qualitative and quantitative factors (Bhutta & Huq, 2002). The overall objective of the supplier evaluation process is to reduce risk and maximize overall value to the purchaser. An effective supplier survey should have certain characteristics such as comprehensiveness, objectiveness, reliability, flexibility and finally, it has to be mathematically straightforward. It can be concluded that important savings can be realized through effective purchasing strategies. This study helps decision makers reduce a base of potential suppliers to a manageable number and make the supplier selection by means of multi-criteria techniques. This new methodology was applied to a car manufacturing facility in Turkey.

2. Literature review

Supplier evaluation is a multi-objective and criteria decision making problem containing many quantitative and qualitative factors because there are typically more than one criterion (attitude) needed to be taken into consideration in evaluating a supply source. All of supply sources are focused on their performance such as delivery, quality, service and price as the main factors that all firms use for evaluating sources of supply (Ha & Krishnan, 2008). Many firms and researchers have been working on the supplier evaluation problem over the past decade to develop decision making models which can effectively deal with this problem. According to Ghodsypour and O'Brien (1998), optimization models for supplier evaluation can be classified into two groups: single objective models which are used to consider one criterion as the objective function and other criteria as constraints. The single objective models have two disadvantages: all criteria are equally weighted, which rarely happens in practice, and they have significant difficulties in considering qualitative factors. In contrast, the multiple objective models have been applied to a supplier evaluation problem. Relying on a single criterion makes the supplier selection process risky. Therefore, a multi-criteria approach is recommended. A pioneering work in supplier selection criteria was that of Dickson in 1966. Despite the multiple criteria nature of the problem, very little work has been devoted to the study of the supplier selection problem by using multi-criteria techniques such as goal programming, multi-objective programming, or other similar approaches. Kahraman, Cebeci, and Ulukan (2003) used fuzzy AHP to select the best supplier for a manufacturer firm established in Turkey. Bevilacqua and Petroni (2002) developed a system for supplier selection using fuzzy logic. Some authors as used in this paper have combined decision models in the supplier selection process, for example, Weber, Current, and Desai (1998) combined DEA and mathematical programming models. This combination provided decision makers with a tool for negotiating with suppliers. Dickson (1966) developed a model combining mathematical programming model and TCO (total cost of ownership). They derived the inventory management policy using activity-based costing information. Ghodsypour and O'Brien (1998) used AHP and mathematical programming to determine the best order quantity allocation while considering qualitative criteria into the analysis. Xia and Wu (2007) presented an integrated approach of AHP improved by rough sets theory and multi-objective mixed integer programming. Dulmin and Mininno (2003) applied a model to a mid-sized Italian firm operating in the field of public road and rail transportation by applying a multi-criteria decision making technique (promethee/gaia) to supplier selection problem. The supplier selection problem is complicated and risky, owing to a variety of qualitative and quantitative factors affecting the decision making process. There have been several supplier selection methods available in the literature. Some authors propose linear weighting models in which suppliers are rated on several criteria and in which these ratings are combined into a single score. These models include the categorical method which relies heavily on the experience and ability of the individual buyer, the weighted point (Timmerman, 1986) and the analytical hierarchical process (Nydick & Hill, 1992). Total cost approaches attempt to quantify all costs related to the selection of a vendor in monetary units, this approach includes cost ratio (Timmerman, 1986) and total cost of ownership (Dulmin & Mininno, 2003). Mathematical programming models often consider only the more quantitative criteria; this approach includes the principal component analysis (Petroni & Braglia, 2000) and neural network (Lovell & Pastor, 1999).

The neural network for supplier selection is another method that has been developed to help selecting the best supplier. Comparing to conventional models for decision support system, neural networks save a lot of time and money of system development. The supplier-selecting system includes two functions: one is the function measuring and evaluating performance of purchasing (quality, quantity, timing, price and costs) and storing the evaluation in a database to provide data sources to neural network. The other is the function using neural network to select suppliers. ANN was also applied to the supplier evaluation problem by imitating the decision process of a buyer for supplier selection (Lovell & Pastor, 1999). Nevertheless, these models are still lacking of the capability to deal with uncertainty which is usually present in the supplier selection problem. Carrera and Mayorga (2008) proposed a Fuzzy Inference System (FIS) approach in supplier selection for new product development. Experts agree that no best way exists to evaluate and select suppliers (Bello, 2003), and thus organizations use a variety of approaches and implements the one that suits best depending on the company's particular requirements. Many previous researches, in vendor evaluation, emphasizes conceptual and empirical decision support models that may suffer from certain shortcomings, such as being mathematically too complex or too subjective. Practical appreciation needs a methodology that is simple to use and understand, but yet it shall produce reasonably accurate results. There have been a lot of hybrid methods employed in the last 10 years at the literature in terms of supplier evaluation and selection methods (Morlacchi, 1999; Simpson, Siguaw, & White, 2003; Weber, Current, & Desai, 2000; Wang, Huang, & Dismukes, 2004; Bello, 2003). Fuzzy AHP, fuzzy TOPSIS and DEA are commonly used in the literature separately or sometimes their combinations can be used at the same time. There has not been any study in the literature about a hybrid fuzzy AHP/fuzzy TOPSIS/DEA approach before. When the literature is widely looked through, MCDM (Multi-Criteria Decision Making) techniques generally used are focused on TOPSIS (or fuzzy TOPSIS), AHP (or fuzzy AHP) and DEA. There have been some advantages and disadvantages when compared with each other, in terms of AHP and TOPSIS (Zeydan & Çolpan, 2009). Also, fuzzy AHP and fuzzy TOPSIS are combined in this study. But, it is the first time in the literature that weights are used by transforming qualitative variables into only one quantitative variable in fuzzy TOPSIS and found as triangular fuzzy numbers with fuzzy AHP. The hybrid method in the first step uses fuzzy AHP to assign criteria weight and then ranks all suppliers for the qualitative selection by using fuzzy TOPSIS. The result obtained from fuzzy TOPSIS is used in DEA as an output variable called quality management system audit (QMSA). In the second step, it uses DEA methodology in order to choose efficient vendors in the final selection process.

3. Proposed hybrid method for supplier selection and evaluation

We used three multi-criteria decision making method to find efficient and inefficient suppliers sensitively. In the first step, these are fuzzy AHP for the determination of criteria weights and fuzzy

TOPSIS to transform the qualitative variables into only one quantitative variable. In the second step, DEA is used for the ranking of efficient and inefficient suppliers. The main aim of using fuzzy logic is that the real world is far from certain. In our daily lives, it is rare to encounter facts that are absolutely true or false. Very often we have to deal with incomplete or uncertain information in solving real world problems, but this uncertain information may contribute towards bad decisions. In order to make the correct decisions in any business, certain and complete data is required. Humans do not need exact information to communicate with each other. We use communication language in terms of the vague linguistic because of its simplicity and accuracy. Real world problems are associated with a matter of degree. Because of its ability to deal with the imprecision, vagueness, and outright lack of information in real world problems, fuzzy sets and fuzzy logic have been extensively studied and employed in many different areas such as decision making, control systems, mathematics, and transportation models (Gomes, Souza, & Vivaldi, 2008).

There are three main steps in the proposed hybrid method such as follows:

1. To determine the criteria weights with fuzzy AHP.
2. To use fuzzy TOPSIS to transform qualitative variables into quantitative data.
3. To find the ranking of efficient and inefficient suppliers.

All steps are explained step by step in Fig. 1.

4. Detailed definition of proposed method

4.1. The use of FAHP methodology for the determination of criteria weights

The weights of criteria as triangular fuzzy numbers (TFN) are found by applying the following steps:

1. Model the problem as a hierarchy containing the decision goal.
2. Establish priorities among the criteria weights of the hierarchy by making a series of judgments based on pair-wise comparisons of the criteria weights.

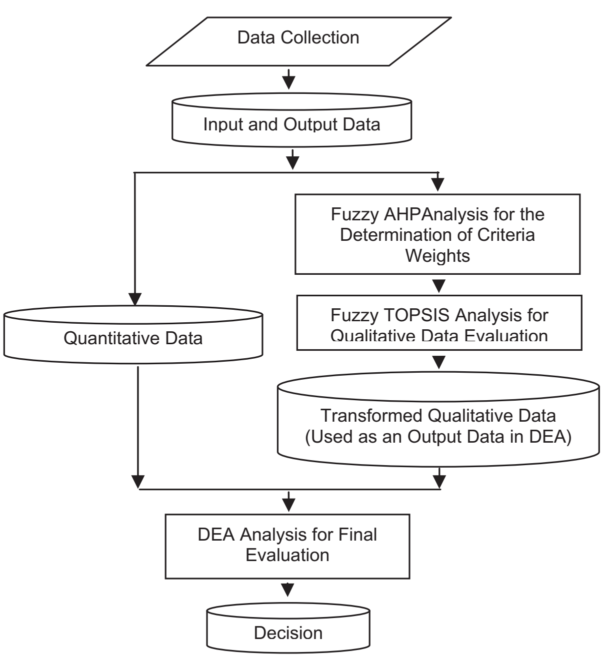

Fig. 1. Flow chart of new methodology.

Table 1
Linguistic variables for weight of each criterion.

Extremely strong	(9, 9, 9)
Intermediate	(7, 8, 9)
Very strong	(6, 7, 8)
Intermediate	(5, 6, 7)
Strong	(4, 5, 6)
Intermediate	(3, 4, 5)
Moderately strong	(2, 3, 4)
Intermediate	(1, 2, 3)
Equally strong	(1, 1, 1)

3. Synthesize these judgments to yield a set of overall priorities for the hierarchy.
4. Check the consistency of the judgments. If consistency ratio is less than 0.1, judgment is true for criteria weights. Afterwards, the scores of pair-wise comparison matrix for criteria weights are transformed into linguistic variables based on Table 1 with the following step 5.
5. The method of Chang's extent analysis which was originally introduced by Chang (1996) is used for finding triangular fuzzy number weights. Let $X = \{x_1, x_2, x_3, \ldots, x_n\}$ an object set, and $G = \{g_1, g_2, g_3, \ldots, g_n\}$ be a goal set

$$M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^m, \quad i = 1, 2, \ldots, n, \tag{1}$$

where $M_{gi}^j (j = 1, 2, \ldots, m)$ all are TFNs.

The value of fuzzy synthetic extent with respect to the ith object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \widetilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n] \tag{2}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, the fuzzy addition operation of m extent analysis values for a particular matrix is performed such as

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{3}$$

And to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, the fuzzy addition operation of M_{gi}^j $(j = 1, 2, \ldots, m)$ values is performed such as

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{4}$$

and then the inverse of the vector above is computed, such as

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{5}$$

Criteria weights are determined at the end of this process as fuzzy triangular number.

4.2. Fuzzy TOPSIS method as qualitative evaluation

After the criteria weights were found, we determine the rating of suppliers. Assume that a decision group has K persons, and then the importance of the criteria and the rating of alternatives with respect to each criterion can be calculated as:

$$\tilde{x}_{ij} = \frac{1}{K} \left[\tilde{x}_{ij}^1 (+) \tilde{x}_{ij}^2 (+) \cdots (+) \tilde{x}_{ij}^K \right] \tag{6}$$

$$\tilde{w}_j = \frac{1}{K} \left[\tilde{w}_j^1 (+) \tilde{w}_j^2 (+) \cdots (+) \tilde{w}_j^K \right] \tag{7}$$

where $\tilde{x}_{ij}^k$ and $\tilde{w}_j^k$ are the rating and the importance weight of the kth decision maker obtained at the end of step 1 and (+) indicates the fuzzy arithmetic summation function. As stated previously, a fuzzy multi-criteria group decision making problem can be concisely expressed in matrix format as:

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad \text{(found by Table 3)} \tag{8}$$

$$\widetilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n] \quad \text{(found by FAHP criteria weights based on Table 1)} \tag{9}$$

where $\tilde{x}_{ij}^k$ and $\tilde{w}_j^k$ are linguistic variables that can be shown by triangular fuzzy numbers: $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$.

To avoid the complicated normalization formula used in classical TOPSIS, the linear scale transformation is used here to transform the various criteria scales into a comparable scale. Therefore, we can obtain the normalized fuzzy decision matrix denoted by $\widetilde{R}$:

$$\widetilde{R} = [\tilde{r}_{ij}]_{m \times n} \tag{10}$$

where B and C are the set of benefit criteria and cost criteria, respectively, and

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), \quad j \in B \tag{11}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right), \quad j \in C \tag{12}$$

$$c_j^* = \max_i c_{ij}, \quad \text{if } j \in B \tag{13}$$

$$a_j^- = \min_i a_{ij}, \quad \text{if } j \in C \tag{14}$$

The normalization method mentioned above is to preserve the property that the ranges of normalized triangular fuzzy numbers belong to [0, 1]. Considering the different importance of each criterion, one can now construct the weighted normalized fuzzy decision matrix as:

$$\widetilde{V} = [\tilde{v}_{ij}]_{m \times n}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{15}$$

where $\widetilde{V}_{ij} = \tilde{r}_{ij}(\cdot)\tilde{w}_j$.

According to the weighted normalized fuzzy decision matrix, we know that the elements $\tilde{v}_{ij}, \forall i; j$, are normalized positive triangular fuzzy numbers and their ranges belong to the closed interval [0, 1]. Then, we can define the fuzzy positive-ideal solution (FPIS, A^*) and fuzzy negative-ideal solution (FNIS, A^-) as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*)$$
$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-)$$

where $\tilde{v}_j^* = (1, 1, 1)$ and $\tilde{v}_j^- = (0, 0, 0)$, $j = 1, 2, \dots, n$.

The distance of each alternative A_i ($i = 1, 2, \dots, m$) from A^* and A^- can be calculated as:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1, 2, \dots, m \tag{16}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots, m \tag{17}$$

where $d(\cdot, \cdot)$ is the distance measurement between two fuzzy numbers.

A closeness coefficient is defined to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i ($i = 1, 2, \dots, m$) has been calculated. The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1, 2, \dots, m \tag{18}$$

Obviously, an alternative Ai is closer to the FPIS (A^*) and farther from FNIS (A^-) as CC_i approaches to 1. Therefore, according to the closeness coefficient, we can determine the ranking order of all alternatives and select the best one from among a set of feasible alternatives.

4.3. DEA method as quantitative evaluation

In this stage, suppliers performance values obtained as a result of fuzzy TOPSIS analysis are considered as an output variable. Supplier's efficiency is calculated with DEA mathematical model below. In our study, results were obtained based on the model of VRS (Variable Returns to Scale)–BCC. A VRS model allows for the level of outputs grow proportionally higher or lower than a corresponding increase in inputs. DEA output-oriented BCC model for decision making units is summarized as follows (Banker, Charnes, & Cooper, 1984):

$$\text{Objective Function} \quad 'E_k = Max\beta + \varepsilon \sum_{i=1}^{m} s_i^- + \varepsilon \sum_{r=1}^{p} s_r^+ \tag{19}$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- - x_{ik} = 0, \quad i = 1, \dots, m \tag{20}$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ - \beta y_{rk} = 0, \quad r = 1, \dots, p \tag{21}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{22}$$

$$\lambda_j \geqslant 0, \quad j = 1, \dots, n \tag{23}$$

$$s_i^- \geqslant 0, \quad i = 1, \dots, m, \quad s_r^+ \geqslant 0, \quad r = 1, \dots, p \tag{24}$$

β is the efficiency score; y_{rj} is the output r for supplier j; x_{ij} is the input i for supplier j; s_i^-, s_r^+ are slack and surplus corresponding to input i, and output r, respectively; λ_j is the weights attached to inputs and outputs of supplier j; x_{ik}, y_{rk} are inputs (i) and outputs (j) of the particular supplier (for k) whose efficiency is being evaluated and ε is a non-archimedean small and positive number.

5. Application in a car factory of proposed supplier selection and evaluation methodology

The firm was established with the partnership share of 30% Turkish and 70% foreign investment in 1997 and it has 100.000 cars per year capacity, and an international car company which uses in 90% of production capacity. 1900 blue collar and 350 white collar employees have worked in the organization and 15% of the white collars are foreign personnel. The company has got factories within seven countries of the world, and production strategies according to the economic structure of countries. This strategy includes the types and amounts of production. A and B model are produced in the factory and 75% of A and 95% of B model is exported foreign countries. According to the production data of the year 2007, market share of the company is about 7% for all cars sold in the world. Components (Items) cost bought by car company per car from suppliers are approximately made up of 70% of total production cost. The purchasing department of factory works based on the following system. Firstly, the components that can be manufactured in Turkey are selected. Secondly, suppliers which have enough capacity to produce these components are determined. That means supplier pool is existed. Then, basic technical drawings are sent to these suppliers and advance proposals are collected from suppliers, this is named as "supplier selection process". After the advance proposals, the first selection is performed and selected the suppliers. After visiting and comparing the suppliers, the second selection is performed. Negotiation as the last stage is made with these selected suppliers and detailed proposals are collected one by one. After the collected detailed proposals, the supplier(s) which gives the best price is selected and started the production process. In the production process, moulds are made or transferred (if the only one production location) and afterwards, pilot car production is made. At the same time, product report related with the component is formed. According to the product report and pilot car production, the first component acceptance is given by quality department. Then, some tests were performed for components. If test results are within the tolerance, mass production is made and line feeding starts for the production. All actions step by step are followed by procurement department until this stage. Then, procurement department follows up price balance of the product. If there comes into existence a problem, the product is interfered. As known, a purchasing department is responsible for ensuring that right products and services are purchased at the right time, the right price, the right quantity, the right quality and from the right sources. Vendor selection criteria as qualitative and quantitative variables for the target company such as follows:

Qualitative variables:

1. New Project Management (C_1): the evaluation of suppliers project studies.
2. Supplier Management (C_2): the evaluation of Tier 2 (supplier of OEM's supplier (2nd level supplier of OEM) system) suppliers.
3. Quality and Environmental Management (C_3): the evaluation of supplier quality and environmental targets and accomplishment status.
4. Production Process Management (C_4): the evaluation of supplier production process and harmony with quality system documents.
5. Test and Inspection Management (C_5): the evaluation of process inspections, periodic tests and equipment calibration status.
6. Corrective&Preventive Actions Management (C_6): the evaluation of supplier claims and countermeasure status.

Quantitative variables:

1. Defect Ratio (PPM): the rejected part ratio in one million. (PPM: Part Per Million).
2. Warranty Cost Ratio (WAR): after sales warranty claim ratio according to sales.
3. Quality Management (QM): the evaluation of supplier mentality.

Concepts of quantitative and qualitative variables are explained in detailed in appendix within questions. Criteria weights and decision matrix are formed according to purchasing and procurement department engineering point of view. Steps of the new methodology are applied as follows:

Step 1. The use of FAHP methodology for determination criteria weights and results.

The hierarchical structure of this decision problem is shown in Fig. 2. The decision makers use the linguistic weighting variables (shown in Table 2) to assess the importance of the criteria and it is presented in Fig. 2 as hierarchy.

To build the pair-wise comparison matrixes, some academics and professionals were worked carefully in the factory. The first four steps of the use of FAHP methodology for the determination of criteria weights are applied according to the AHP analysis for consistency. The most important stage of the fifth step which is the pair-wise comparison matrix for the criteria weights as fuzzy triangular number is established in Table 2.

The values of fuzzy synthetic extents with respect to the criteria weights are calculated as below (see Eq. (2)):

$$S_A = (2.08, 2.43, 3.25) \otimes (1/72.09, 1/55.01, 1/40.53) = (0.029, 0.044, 0.080)$$

$$S_B = (9.33, 12.50, 16.00) \otimes (1/72.09, 1/55.01, 1/40.53) = (0.129, 0.227, 0.395)$$

$$S_C = (3.12, 4.58, 6.83) \otimes (1/72.09, 1/55.01, 1/40.53) = (0.043, 0.083, 0.169)$$

$$S_D = (13.00, 18.00, 23.00) \otimes (1/72.09, 1/55.01, 1/40.53) = (0.180, 0.327, 0.568)$$

$$S_E = (7.33, 9.50, 12.00) \otimes (1/72.09, 1/55.01, 1/40.53) = (0.102, 0.173, 0.296)$$

$$S_F = (5.67, 8.00, 11.00) \otimes (1/72.09, 1/55.01, 1/40.53) = (0.079, 0.145, 0.271)$$

Fuzzy criteria weights are found with the use of FAHP methodology such as follows:

$$W_A = (0.029, 0.044, 0.080); \quad W_B = (0.129, 0.227, 0.395); \quad W_C = (0.043, 0.083, 0.169)$$

$$W_D = (0.180, 0.327, 0.568); \quad W_E = (0.102, 0.173, 0.296); \quad W_F = (0.079, 0.145, 0.271)$$

Triangular fuzzy numbers found at the end of step 1 will be accepted as weight values of qualitative criteria and used in fuzzy TOPSIS methodology.

Step 2. The use of fuzzy TOPSIS and results.

In this step, fuzzy TOPSIS will be used for transforming qualitative variables into only one quantitative variable as an output variable called QMSA (Quality Manufacturing System Audit) such as follows:

a. The decision makers use the linguistic rating variables (shown in Table 3) to evaluate the rating of alternatives with respect to each criterion and present it in Table 4.
b. Converting the linguistic evaluation (shown in Table 4) into triangular fuzzy numbers to construct the fuzzy decision matrix and determine the fuzzy weight obtained with FAHP of each criterion as Table 5.
c. Constructing the normalized fuzzy decision matrix as Table 6 (see Eq. (10)).
d. Constructing the weighted normalized fuzzy decision matrix as Table 7 (see Eq. (15)).
e. Determine FPIS and FNIS as:

$$A^* = [(1,1,1), (1,1,1), (1,1,1), (1,1,1), (1,1,1)]$$
$$A^- = [(0,0,0), (0,0,0), (0,0,0), (0,0,0), (0,0,0)]$$

f. Calculate the distance of each candidate from FPIS and FNIS, respectively, as Tables 8 and 9.
g. Calculate d_i^* and d_i^- of seven possible suppliers A_i ($i = 1, 2, \ldots, 7$) as Table 10 (see Eqs. (16) and (17)).
h. Calculate the closeness coefficient of each candidate as (see Eq. (18))

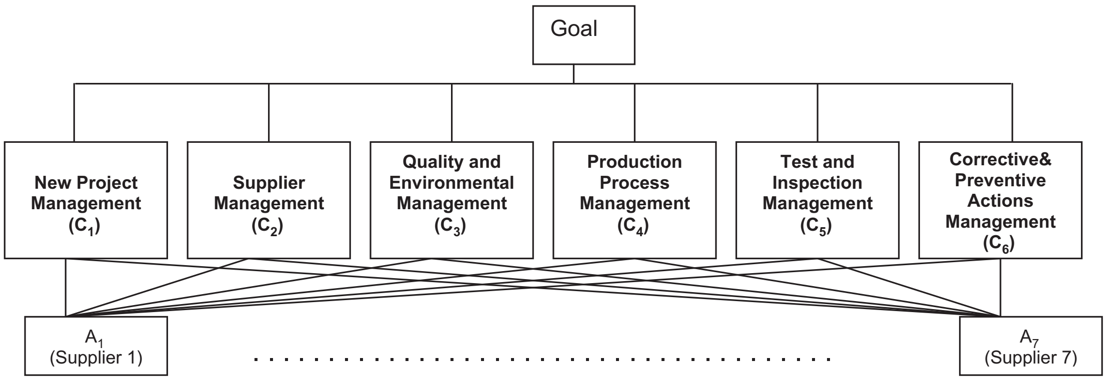

Fig. 2. Hierarchical structure.

Table 2
Fuzzy pair-wise comparison matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/3, 1/1/2, 1/1)	(1/8, 1/7, 1/6)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)
C_2	(4, 5, 6)	(1, 1, 1)	(2, 3, 4)	(1/3, 1/2, 1/1)	(1, 1, 1)	(1, 2, 3)
C_3	(1, 2, 3)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1/1)	(1/3, 1/2, 1/1)
C_4	(6, 7, 8)	(1, 2, 3)	(3, 4, 5)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)
C_5	(3, 4, 5)	(1, 1, 1)	(1, 2, 3)	(1/3, 1/2, 1/1)	(1, 1, 1)	(1, 1, 1)
C_6	(2, 3, 4)	(1/3, 1/2, 1/1)	(1, 2, 3)	(1/3, 1/2, 1/1)	(1, 1, 1)	(1, 1, 1)

Table 3
Linguistic variables for the ratings.

Very good (VG)	(9, 10, 10)
Good (G)	(7, 9, 10)
Medium good (MG)	(5, 7, 9)
Fair (F)	(3, 5, 7)
Medium poor (MP)	(1, 3, 5)
Poor(P)	(0, 1, 3)
Very poor (VP)	(0, 0, 1)

Table 4
The ratings of the seven candidates by decision makers under all criteria.

Suppliers	Criteria					
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	MG	G	G	MG	MG	G
A_2	MG	MG	MG	MG	MG	MG
A_3	MG	MG	MG	MG	MG	G
A_4	F	F	F	F	F	MG
A_5	MG	MG	MG	MG	MG	G
A_6	MG	MG	MG	MG	MG	G
A_7	MG	MG	F	F	MG	MG

$$CC_1 = 0.1783; \quad CC_2 = 0.1685; \quad CC_3 = 0.1706;$$
$$CC_4 = 0.1328; \quad CC_5 = 0.1706; \quad CC_6 = 0.1706; \quad CC_7 = 0.1529$$

In Table 10, QMSA is found by accepting that the biggest ratio of CC_i (0.1783) is the point 100. To find the other QMSA values, QMSA is compared to CC_i.

At the end of the second step, firstly, criteria weights based on six qualitative variables are calculated with FAHP methodology as Triangular fuzzy number. Secondly, according to fuzzy TOPSIS method, qualitative variables are transformed into only one quantitative variable as an output called quality management system audit (QMSA) and will be used in DEA as an output.

Step 3. Finding the ranking of efficient and inefficient suppliers with DEA and final results.

In this step, supplier performance values obtained as a result of fuzzy TOPSIS analysis are considered as the fourth output variable called QMSA. Input and output values collected from the purchasing and quality records are given in Table 11. Since the factory focus on the final product, we ignore the company inputs. To measure the efficiency of each supplier we assume unitary inputs for all units. In DEA, at least one input (dummy) that has a value of 1 for all suppliers should be used together with outputs since analysis cannot be made solely based on outputs properly (De Koeijer, Wossink, Struik, & Renkema, 2002; Leta, Soares de Mello,

Table 5
The fuzzy decision matrix and fuzzy weights of eight alternatives.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(5, 7, 9)	(7, 9, 10)	(7, 9, 10)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
A_2	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
A_3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
A_4	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)
A_5	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
A_6	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 10)
A_7	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)
Weight	(0.029, 0.044, 0.080)	(0.129, 0.227, 0.395)	(0.043, 0.083, 0.169)	(0.180, 0.327, 0.568)	(0.102, 0.173, 0.296)	(0.079, 0.145, 0.271)

Table 6
The fuzzy normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(0.5, 0.7, 0.9)	(0.7, 0.9, 1)	(0.7, 0.9, 1)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1)
A_2	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
A_3	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1)
A_4	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)
A_5	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1)
A_6	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1)
A_7	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)

Table 7
The fuzzy weighted normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(0.014, 0.031, 0.072)	(0.091, 0.205, 0.395)	(0.030, 0.075, 0.169)	(0.090, 0.229, 0.511)	(0.051, 0.121, 0.267)	(0.055, 0.131, 0.271)
A_2	(0.014, 0.031, 0.072)	(0.065, 0.159, 0.355)	(0.022, 0.058, 0.152)	(0.090, 0.229, 0.511)	(0.051, 0.121, 0.267)	(0.039, 0.102, 0.244)
A_3	(0.014, 0.031, 0.072)	(0.065, 0.159, 0.355)	(0.022, 0.058, 0.152)	(0.090, 0.229, 0.511)	(0.051, 0.121, 0.267)	(0.055, 0.131, 0.271)
A_4	(0.009,0.022,0.056)	(0.039, 0.114, 0.276)	(0.013, 0.042, 0.118)	(0.054, 0.164, 0.397)	(0.031, 0.086, 0.207)	(0.039, 0.102, 0.244)
A_5	(0.014, 0.031, 0.072)	(0.065, 0.159, 0.355)	(0.022, 0.058, 0.152)	(0.090, 0.229, 0.511)	(0.051, 0.121, 0.267)	(0.055, 0.131, 0.271)
A_6	(0.014, 0.031, 0.072)	(0.065, 0.159, 0.355)	(0.022, 0.058, 0.152)	(0.090, 0.229, 0.511)	(0.051, 0.121, 0.267)	(0.055, 0.131, 0.271)
A_7	(0.014, 0.031, 0.072)	(0.065, 0.159, 0.355)	(0.013, 0.042, 0.118)	(0.054, 0.164, 0.397)	(0.051, 0.121, 0.267)	(0.039, 0.102, 0.244)

Table 8
Distances between A_i ($i = 1, 2, \ldots, 7$) and A^* with respect to each criterion.

	C_1	C_2	C_3	C_4	C_5	C_6	d^*
$d(A_1, A^*)$	0.9612	0.7802	0.9105	0.7442	0.8586	0.8355	5.0901
$d(A_2, A^*)$	0.9612	0.8160	0.9244	0.7442	0.8586	0.8499	5.1542
$d(A_3, A^*)$	0.9612	0.8160	0.9244	0.7442	0.8586	0.8355	5.1398
$d(A_4, A^*)$	0.9713	0.8628	0.9435	0.8078	0.8950	0.8676	5.3479
$d(A_5, A^*)$	0.9612	0.8160	0.9244	0.7442	0.8586	0.8355	5.1398
$d(A_6, A^*)$	0.9612	0.8160	0.9244	0.7442	0.8586	0.8355	5.1398
$d(A_7, A^*)$	0.9612	0.8160	0.9435	0.8078	0.8586	0.8499	5.2369

Table 9
Distances between A_i ($i = 1, 2, \ldots, 7$) and A^- with respect to each criterion.

	C_1	C_2	C_3	C_4	C_5	C_6	d^-
$d(A_1, A^-)$	0.0461	0.2620	0.1080	0.3274	0.1715	0.1895	1.1044
$d(A_2, A^-)$	0.0461	0.2279	0.0947	0.3274	0.1715	0.1773	1.0448
$d(A_3, A^-)$	0.0461	0.2279	0.0947	0.3274	0.1715	0.1895	1.0569
$d(A_4, A^-)$	0.0352	0.1740	0.0727	0.2500	0.1308	0.1562	0.8189
$d(A_5, A^-)$	0.0461	0.2279	0.0947	0.3274	0.1715	0.1895	1.0569
$d(A_6, A^-)$	0.0461	0.2279	0.0947	0.3274	0.1715	0.1895	1.0569
$d(A_7, A^-)$	0.0461	0.2279	0.0727	0.2500	0.1715	0.1773	0.9454

Table 10
The distance measurement.

	d^*	d^-	$d^* + d^-$	CC_i	QMSA
A_1	5.0901	1.1044	6.1945	0.1783	100.00
A_2	5.1542	1.0448	6.1991	0.1685	94.54
A_3	5.1398	1.0569	6.1968	0.1706	95.67
A_4	5.3479	0.8189	6.1668	0.1328	74.48
A_5	5.1398	1.0569	6.1968	0.1706	95.67
A_6	5.1398	1.0569	6.1968	0.1706	95.67
A_7	5.2369	0.9454	6.1824	0.1529	85.78

Table 11
Input and output data for suppliers (the year 2007).

Suppliers	Input	Outputs			
		QMSA	PPM	QM	WAR
A_1	1	100.00	16.15	5	19.82
A_2	1	94.54	4.24	5	8.08
A_3	1	95.67	18.43	8.5	19.93
A_4	1	74.48	18.34	3	20
A_5	1	95.67	17.96	8.8	20
A_6	1	95.67	18.91	4	20
A_7	1	85.78	19.89	4	20

Table 12
Output-oriented BCC reference set and efficiency of suppliers.

Suppliers	Efficiency	Reference frequency	Reference set	Rank
A_1	104.53	1		2
A_2	94.83		A1 (0.93), A_5 (0.07)	Inefficient
A_3	101.63	0		4
A_4	100.00		A_5 (0.47), A_6 (0.25), A_7(0.28)	Inefficient
A_5	103.53	2		3
A_6	101.47	1		5
A_7	105.19	1		1

Gomes, & Meza, 2005; Ramanathan, 2006; Wei, Zhang, & Li, 1997; Zimmermann, 1985). The model we consider here is BCC with output orientation.

Reference set and the efficiency of all suppliers obtained are shown in Table 12 after DEA analysis of this system is performed in the EMS (Efficiency Measurement System) version 1.3 software package according to super efficiency model. Since the DEA-CCR (Charnes–Cooper–Rhodes) and DEA-BCC models are weak in discriminating between efficient suppliers (Andersen & Petersen, 1993), analysing the hybrid fuzzy AHP/fuzzy TOPSIS-DEA model (for qualitative and quantitative values) is used the super efficiency model for comparing the efficient suppliers with each other as shown in Table 12.

As an example, Table 13 provides detailed calculations of supplier A_2's composite supplier from the reference set of suppliers for the year 2007. The composite of supplier A_2 in 2007 is formed from the weighted average of best-practice supplier in the efficiency frontier of supplier A_2 i.e. supplier A_1 (0.93 A_1), supplier A_5 (0.07 A_5). supplier A_2's comparative efficiency rating of 94.83% indicates the extent to which the efficiency of supplier A_2 is lacking in comparison to the efficiency of its reference set of suppliers.

Table 13
Computation of the composite reference set for supplier A_2.

	Real value	Reference set				Target value	Potential improvement
	A_2	λ_1	A_1	λ_5	A_5	$A_2^* = \lambda_1 * A_1 + \lambda_5 * A_5$	$(A_2^* - A_2)/A_2$ (%)
Input	1		1		1	1	0.00
QMSA	94.54		100		95.67	99.70	5.45
PPM	4.24	0.93	16.15	0.07	17.96	16.28	283.88
QM	5		5		8.8	5.27	5.32
WAR	8.08		19.82		20	19.83	145.45

Table 14
Potential Improvement of inefficient suppliers.

Suppliers	Input		QMSA		PPM		QM		WAR	
	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target
A_2	1	1	94.54	99.70	4.24	16.28	5	5.27	8.08	19.83
A_4	1	1	74.48	92.90	18.34	18.74	3	6.26	20	20

Supplier A_2 is 94.83% as efficient as its reference set of suppliers (A_1, A_5). This efficiency reference set of suppliers represent the basis vector in the linear program solution for supplier A_2. That is, a convex combination of the actual outputs and inputs of the reference subset of suppliers results in a composite supplier that produces as much or more outputs as supplier A_2, but uses as much or less inputs than supplier A_2. In order to be able to increase the efficiency of A_2, target values and potential improvements are calculated and shown in Table 14 which documents the values of deficient inputs and excess outputs that existed within supplier A_2 in the year 2007.

6. Discussion and conclusion

In this study, a new methodology is introduced and was applied in a car manufacturing factory for the selection and evaluation of quality supplier(s). According to the solution of aforementioned analysis, two suppliers (A_2, A_4) are defined as "non-efficient" vendors in manufacturing the luggage side part (panel). Hence, other five suppliers (A_1, A_3, A_5, A_6, A_7) are the candidates which will be chosen for buying these components and will be able to join the bidding system for manufacturing luggage side panel. At the end of this evaluation process, the supplier which will be able to give the best price will be selected for luggage side panel production after the bidding and negotiation meeting.

The OEM (Original Equipment Manufacturing) has its own supplier evaluation system as other OEMs have. According to the running system in the factory, after the yearly evaluation, suppliers should increase their performance and prove them with evaluation items. The most important evaluation item for the OEM is Quality Management System Audit which is qualitative, but this system audit is transformed into a quantitative result by a specific evaluation sheet on the basis of item points as shown in appendix (each supplier is audited once in a year). After performing an audit, improvement points are listed with a pictured audit report which is based on "Before–After" system. Supplier should reply the audit report within 15 days and put the pictures for closed actions. If an action closing requires more time, supplier needs a target date for unclosed actions and should close it on time. If not, the related audit item, Corrective&Preventive Actions Management, score will be "zero" and other related items, e.g. Quality and Environmental Management, will be low scored according to current audit situation. Hence, it will reduce next audit score and supplier will have disadvantages for the new projects.

In general, the car company will ask for quotations from all seven suppliers and will have negotiation meetings with all of them. One supplier will be eliminated in each step and finally one supplier will be selected, but this will take almost two months which is very short duration for seven different quotation evaluations. Hence, supplier selection will be made in rush and some important cost and price items will be missed due to job stress caused by short supplier selection period. On the other hand, the car factory can prolong this period, but it will cause project to be delayed. At this point, our study will be a helpful sample for the other implementing businesses since ineffective suppliers (A_2, A_4) will be directly removed from part producer pool and quotation will not be requested from them. So, five suppliers will present their quotations and join the negotiation meetings. Consequently, two months quotation evaluation and supplier selection period will be used more effective.

In the current running system, supplier quality level is used for supplier selection as qualitative when two suppliers have very close, similar quotation. For this reason, suppliers are informed and invited to present their final quotation. If there is not a reasonable difference between their prices given, supplier whose quality level is high is selected as part producer. Otherwise, supplier which gives the best price for the part is selected as supplier. In our application, current supplier for car luggage side part (panel) is supplier A_7 for A type car. This situation shows that supplier A_7 gave the best price for the part and got the project, but none of quality evaluation was done before project was given to the supplier A_7 except pre-mass production. In the history, we see that suppliers A_4, A_6, and A_7 presented their quotations. The price sequence is (from lower to higher) occurred like suppliers A_7, A_6, and A_4. According to our study, supplier A_4 would directly be eliminated from the list before company requested part quotations and suppliers A_7 and A_6 would be focused. Consequently;

- Supplier A_7 was chosen as the supplier for company.
- Supplier A_6 would be chosen as supplier according to our study.

Quality performance of both suppliers in the year 2008 is shown in Table 15.

Supplier A_6 is better than supplier A_7 according to quality performance indicator of the year 2008. If we think that the rejected parts are scrapped, this is a very important result because the loss of supplier A_6 caused by rejected parts is reasonable to think provided that the production of luggage side part is feasible. As a mat-

Table 15
Quality performance indicator (PPM) of the year 2008.

Suppliers	Part reject status (2008)		
	Accept	Reject	PPM
A_6	463,148	262	566
A_7	260,633	348	1335

ter of fact, part rejects are the biggest portion of problems as supplier looses money and it requests cost increase to be able to compansate its loss. This can take the company to make source change which is transferring the part to another supplier because OEMs do not want to increase part prices unless any unexpected things happen (e.g. raw material increase). Supplier assures part quality before starting the project and can not request any extra money (cost) about part defects and repairs.

This analysis also shows us qualitative and quantitative outputs are not the exact decision making tools alone. According to the qualitative evaluation, company should choose A_1 as supplier, but this time it should be ready to face with potential part problems such as PPM. On the other hand, according to quantitative evaluation, company should choose supplier A_7, but that time it should be careful about the quality system of supplier and be ready to face with part problems, because PPM and warranty claim problems have direct connection with poor process development. Process development is placed in supplier quality system. If potential problems can not be caught during project development stage, it will bring lots of problems and concerns. Hence, before the supplier selection and evaluation, both qualitative and quantitative indicators should be considered together and combined. So, risks will be not only minimized and but also be analyzed efficiently and effectively.

Acknowledgements

The authors would like to express their special thanks to the international car manufacturing firm management and their staff because of their valuable contributions in collecting all data and information which was required.

Appendix A. Supplier evaluation criteria and points of each criteria and item

(C_1). New Project Management (100)

1. Procedure control for the advanced quality planning for new project parts. (50)
   * Advanced quality planning including customer and sub-vendor development schedule is insufficient. (10)
   * Advanced quality planning including customer and sub-vendor development schedule has been established, requirement for plan and actual are insufficient. (20)
   * Advanced quality planning including customer and sub-vendor development schedule has been established progress review by plan and actual status is insufficient. (30)
   * Advanced quality planning including customer and sub-vendor development schedule has been established work focused on design/development has been progressed. (40)
   * CFT approach for new part development system by new car quality team, has been organized and performed well. Top management report and support have been performed frequently. (50)
2. Verification and detailed review of product/process. (50)
   * Advanced quality planning and procedure reflecting project phases is insufficient. (10)
   * Old model history master list and improvement status, FMEA, verification of detail requirement is insufficient. (20)
   * Advance planning phases, requirements, review of product/process has been performed well, but quality records are insufficient. (30)
   * Advance planning phase requirements, review of product/process has been performed well, but total activity result insufficient practice result is insufficient. (40)
   * New parts quality assurance before mass production is performed, after mass production the system of parts development history is satisfied. (50)

(C_2). Supplier Management (150)

1. Controlling PPAP and PPAP process with the suppliers. (50)
   * Some items' AOI not approved. (10)
   * All AOI's available but not approved. (20)
   * All AOI's approved but PPAP (Production Part Approval Process) not properly done. (30)
   * All AOI's/inspection standard and PPAP done within customer development schedule. (40)
   * All AOIs / quality agreement approved by Research&Development within customer development schedule. (50)
2. Controlling incoming inspection procedure preparation and implementation. (50)
   * Incoming inspection procedure not prepared and implemented. (10)
   * Incoming inspection procedure not prepared and implemented for some products. (20)
   * Incoming inspection not implemented for some products. (30)
   * All incoming inspection done (inspection and non-inspection item, gage inspection). (40)
   * All incoming inspection done excellent and the Statistical Process Control of main parts controlled. (50)
3. Controlling sub-vendor (supplier) evaluation system. (50)
   * Sub-vendor periodical evaluation plan has not been established. (10)
   * Periodical evaluation plan has been established but selection/new registration evaluations are insufficient. (20)
   * Sub-vendor periodical evaluation plan has been established and performed, but distribution of audit finding list, counter measures are insufficient. (30)
   * Counter measure of periodical evaluation has been registered and counter measure has been collected. New supplier selection/new registration evaluation has been performed in procedure. (40)
   * Evaluation system continuous improvement and quality improvement have been collected, quality level has been increased. (50)

(C_3). Quality and Environmental Management (150)

1. Quality/environment target and achievement control. (50)
   * Quality/environment target has been achieved, but established reasons are insufficient. (10)
   * Quality/environment target list are very different, and revision of change has not controlled. (20)
   * Details of action plan for quality/environment target have been established, but they are not performing. (30)
   * Quality/environment target has been performed according to details of action plan, and regular achievement to the target has been monitored/reviewed and controlled. (40)
   * Counter measure for shortage to the target has been established and achievement indicator has been improved. (50)

2. Control of safety and 5S issues. (50)
   ** 0 point for dissatisfied items.
   * 5S activity being done and evaluated on a regular basis, continuos improvement being done. (5)
   * 5S of equipment and workplace have been performed, and cleanness has been maintained. (5)
   * Good lighting in shop floor/no noise/smell/dust in process are not difficult to work. (5)
   * Tool/mould/die are well arranged, properly identified and stored with identification tag. (5)
   * Supplier parts storage 5S, FIFO well maintained. (5)
   * The safety rule of shop floor is displayed and followed. (5)
   * Reducing pollution substance plan and production control system has been established. (10)
   * Separate collection, place of waste material identification and control is good. (10)
3. Control of products (sub-vendor parts/WIP/finished) about preventing damage, FIFO and lot traceability. (50)
   ** 0 point for dissatisfied items.
   * No damage and deformation/storage area fixed and managed well periodical evaluation of storage for damages/has been performed. (10)
   * Cleanness of pallet/box, truck and damage, deformation, interference, over loading have been prevented. (10)
   * During moving between process, route card and delivery card, label has been used. (10)
   * Products (incoming/process/finished) FIFO system has been established and FIFO has been performed. (10)
   * Finished products including major sub-vendor parts have been controlled by lot control and follow-up control, quality problem solutions have been performed. (10)

(C_4). Production Process Management (300)

1. Quality document control (process FMEA, control plan, work standard). (60)
   * Only part of process FMEA has been written and quality documents has not been linked with other documents. (12)
   * All of process FMEA have been performed but control of the latest quality documents has not been linked. (24)
   * Among quality documents, linking is done, but identification and establishment of control lists and criteria are insufficient. (36)
   * Establishment, reflection of counter measure in accordance with rpn and identification of control list and control criteria are appropriate. (48)
   * Various activities for reducing rpn has been performed continuously, and revision control of quality documents, linking of documents are good. (60)
2. SPC and special characteristic's control. (60)
   * Special characteristic about products and process and key control parameters are not identified. (12)
   * Special characteristic and key control parameter have been identified but there is no control criteria. (24)
   * Control criteria including SPC have been established and performed. (36)
   * Control of special characteristic and key control parameter has been satisfied in control range. (48)
   * SPC tool used for process control/analysis tools used for solving problems/problems not repeated. (60)
3. Working conditions, tool change, parameter set up condition. (60)
   * Work condition control criteria has not been established and not meeting the standards. (12)
   * Some processes do not meet work condition and inspection result of work condition is insufficient. (24)
   * Work condition confirms to standards and inspection result has been performed, but when work change, verification or try-out is insufficient. (36)
   * When work change, as verification or try-out has been performed, work condition has met the standards and optimized work condition has been established. (48)
   * Periodical verification of equipment reliability has been performed and it synchronized with present work condition. (60)
4. Equipment Maintenance system (60)
   * Daily equipment check has not been performed and establishing equipment maintenance plan according to procedure is insufficient. (12)
   * Daily check is performed and check sheet not recorded. (24)
   * Visual check points, numerical values are recorded for daily check and equipment maintenance plan has been established, but implementation is insufficient. (36)
   * Maintenance activity in accordance with plan has been performed and equipment record like breakdown/repairing time has been controlled. (48)
   * Continuous improvement for increasing production ability and operation rate has been performed. (60)
5. M Change History Management (60)
   * Raw materials and supplier change without report and 4 m change approval (0)
   * Documentation of procedure for 4 M change is insufficient/control of 4 M record has not been performed. (12)
   * 4 M change has followed the procedure, but it is perfunctory. (24)
   * 4 M change followed, but supplier 4 M change is insufficient. (36)
   * 4 M change has been reviewed and approved, but its record is insufficient. (48)
   * 4 M change has been reviewed and approved, also its record has been controlled/revision of other quality documents has been controlled. (60)

(C_5). Test and Inspection Management (240)

1. In-process inspection system. (60)
   * Process inspection (frequency/patrol) system has been established but it has not been performed. (12)
   * Some of process inspections have been omitted or are perfunctory/nonconforming products have not been identified and isolated. (24)
   * Process inspection has been performed in accordance with criteria, its record also has been established, and nonconforming products have been identified and isolated. (36)
   * Require measurement for assurance of process inspection reliability has been held and identified when rework, reinspection is performed by inspector. (48)
   * Efficiency of process inspection for inspection procedure (list, method, period) improvement has been performed and there are reasons of improvement performance. (60)
2. Final Product Control. (60)
   * Finished product inspection system has been established, but it has not been performed. (12)
   * Finished product inspection has been performed perfunctorily and identifying and isolating nonconforming products are insufficient. (24)
   * Finished product inspection to some important inspection list has been performed and its record has been written, nonconforming products have been identified and isolated. (36)
   * Inspection list agreed with customers has been performed 100%, methods and equipments for inspection detect improvement have been applied. (48)

  * Efficiency of process inspection for inspection procedure (list, method, and period) improvement has been evaluated and there are improvement reasons. (60)
3. Regular Test Plan. (60)
  * Regular inspection plan has not been established. (12)
  * Regular inspection plan has been established, but performance is insufficient and limit durability test has not been performed. (24)
  * Regular inspection has been performed according to inspection agreement without omission. (36)
  * Regular inspection is fine, cause analysis to rejection and limit durability test has been performed its result has been controlled. (48)
  * List 4 is satisfied, details of regular inspection for reliability have been reviewed and feasibility studies have been controlled continuous. (60)
4. Calibration&Validation System. (60)
  * Inspection/measuring tools, inspection/experiment tools haven't been provided and calibration plan has not been established. (12)
  * Inspection/measuring tools, inspection/experiment tools have been provided and calibration plan has been established. (24)
  * Calibration has been performed in accordance with plan, but maintenance and management are insufficient. (36)
  * Calibration has been performed without omission, keeping and management condition is fine. (48)
  * Providence of necessity, calibration record has been performed, and periodical experimentability has been grasped and controlled. (60)

(C_6). Corrective&Preventive Actions Management (60)

Problems and preventive actions situation

* Quality problems states by divisions have been grasped and registered. (12)
* Cause analysis of quality problems, counter measure have been established, but details are insufficient and perfunctory. (24)
* Correction including 3D (Dimension) counter measures has been established by division and controlled horizontal unfolding to similar quality problems. (36)
* Efficiency verification policy to correction result has been established and grasped. (48)
* After efficiency verification, prevention measures for preventing reoccurrence have been established, and periodical achievement indicator, continuous improvement has been performed. (60)

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