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Full Length Research Paper

Achieving green outsourcing performance in uncertainty

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The international business environments advocate green outsourcing performance (GOP) as fundamental enablers and criteria for the competitiveness of original equipment manufacturing (OEM) firms. Few studies providing integrated competitive advantages, enablers and criteria (called measures), exist, and are suitable for practical adoption to enhance GOP. This study presents an original approach to identify the most appropriate method that firms should implement, starting from competitive advantages to internal processes in an intensive market. The approach is based on quality function deployment (QFD), and in particular, all measures with interdependence relationships are given qualitative preferences, which are rarely applied in the literature. The whole scaffold exploits fuzzy set theory and analytical network processes to translate linguistic preferences required for interdependence relationships into numerical values; the QFD translates the result into a final criteria ranking system. A case study, grounded on data available from an OEM electronic firm, is proposed and discussed to show the application of the developed tool.

Key words: Quality function deployment, green outsourcing performance, analytical network process, fuzzy set theory.

INTRODUCTION

Green outsourcing performance (GOP) evaluation of an original equipment manufacturing (OEM) firm is an on-going process that requires continuous monitoring to maintain high levels of internal process evaluation across a number of implementation enablers and criteria in the organization. Increased outsourcing of manufacturing activities has become a prominent part of the restructuring of firms' supply chains since the 1990s. Many academic and consulting firms seem to support the view of outsourcing as one of the key drivers of superior performance (Kotabe et al., 2008; Cheng and Lee, 2010). Nowadays, green practice is also an overall strategic organizational approach for designing green product and waste elimination processes due to mandated environmental orders from the European Union such as waste electrical and electronic equipment (WEEE) and restriction of hazardous substances (ROHS) directives (Tseng et al., 2008). Therefore, an effective and structured GOP evaluation for OEM firms needs to be developed.

Without proper GOP evaluation, it is extremely difficult to exploit potential markets around the world. As a result, the increasing pace of green practices leads time, and calls for more proactive evaluation of GOPs on building up competitive advantages (Li et al., 2006; Tseng, 2010). However, GOP evaluation depends upon integrating wider enablers and criteria to lower the environmental impact of a firm. Various studies argue that manufacturing decisions and choices have to be consistent with green corporate strategy for effective environmental management (Iyer et al., 2006; Tseng et al., 2008a, 2008b; Tseng and Lin, 2008; Lee et al., 2009; Lin et al., 2010). Therefore, firms must integrate GOP enablers and criteria and enhance their competitive advantages to ensure corporate survival toward sustainable development (Tseng et al., 2008, 2009a, b; Lin et al., 2010). However

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2010). However, even fewer studies exist that deal with interdependence relationships in achieving GOP with qualitative measures to carry out measurement activities and implementation into an OEM firm.

Nevertheless, the tasks of OEM firms aim to satisfy the customer at the very beginning, which is, the green product design stage. In particular, quality function deployment (QFD) is one of these techniques for designing the needs of customers into practical measures. This approach enables firms to be proactive to customer satisfaction rather than taking a reactive position by acting on customer complaints (Karsak, 2002; Tsai et al., 2003; Bevilacqua et al., 2006). Various companies immediately adapted QFD, but it did not draw much public attention. QFD was implemented at the Kobe shipyards of Mitsubishi Heavy Industries Ltd. Although it was implemented successfully throughout Japan, it remained solely as a Japanese tool until the early 1980s. There have been studies on quantifying the planning issues of house of quality (HOQ) within the past decade, which mainly focus on customer needs. Khoo and Ho (1996), Chan et al. (1999) and Lin et al. (2010) employ fuzzy set theory to rate customer needs. Other researchers use the analytic hierarchy process (AHP) to determine the degree of importance of customer needs (Park and Kim, 1998). With QFD, OEM firms can evaluate their criteria in terms of their effectiveness in creating value for achieving GOP to develop internal cap abilities necessary to improve future performance.

In addition, QFD is applied to plan and design green products. It employs cross-functional enablers to determine customer needs and translates them into green product designs through a structured analysis (Crowe and Cheng, 1996; Han et al., 1998; Chan and Wu, 2002). Hence, in real situations, cross-functional enablers are involved in interdependence relations when evaluating the GOP of an OEM firm. In view of the inter dependence complexity, evaluation of GOP would anticipate multi-dimensional difficulties. Moreover, some of the qualitative measures are presented in linguistic expressions. The linguistic expressions are vague and uncertain in nature, which makes the evaluated measures with interdependence relations (called network relations) even more challenging.

The traditional statistical approach is no longer suited to evaluate proposed network QFD because the traditional approach always assumes that the enablers and criteria are independent. Yet, the evaluating firm's activities have inherent and high uncertainty and imprecision and are difficult to assess accurately with qualitative information. Previous studies have identified various evaluation methods. Kotabe et al. (2008) proposed a dynamic perspective on outsourcing strategy and its performance implications and argued that there is an optimal degree of outsourcing. The outsourcing-performance relations take on an inverted-U shape, implying that as firms deviate further from their optimal degree of outsourcing, by either insourcing or outsourcing too much, their performance will suffer disproportionately. Chen and Lee (2009) studied how reverse logistics are increasingly crucial for the supply chain strategy of global high-tech manufacturing firms and presented a systematic approach using analytical network process (ANP) not only to investigate the relative importance of reverse logistics service requirements but also to select an appropriate third party logistics provider. Dabhilkar *et al*. (2009) presented an empirical study designed to determine factors for performance improvement when outsourcing manufacturing. They found that operations in low-cost countries can improve one performance dimension, and part characteristics and supplier oprating capabilities are more important than supplier relationship strategies when outsourcing manufacturing, meaning that supplier selection trumps supplier collaboration in the make-or-buy decision. However, none of them cosidered the uncertain nature of qualitative preferences and voices of customers simultaneously. This study proposes to utilize fuzzy set theory, the ANP technique and QFD to achieve GOP. The ANP developed by Saaty (1996) takes into account both the relationships of feedback and dependence. In addition to these merits, ANP provides a more generalized model for decision-making without making assumptions about interdependence relations among competitive advantages, enablers and criteria (GOP measures) in qualitative preferences.

In view of qualitative preferences, fuzzy set theory can address situations that lack well-defined boundaries of activity or observation sets (Zadeh, 1965; 1975). In many practical cases, the human subjective is uncertain and qualitatively descriptive, and it is not easy to assign exact numerical values to precisely describe linguistic preferences. Linguistic terms have been used for approximate reasoning within the framework of fuzzy set theory to handle the ambiguity of evaluating data and the vagueness of linguistic expression. Hence, fuzzy set theory can express and handle vague or imprecise judgments mathematically (Al-Najjar and Alsyouf, 2003; Tseng and Lin, 2008; Tseng *et al*., 2009b). A linguistic preference is a variable whose values (namely linguistic values) have the form of phrases or sentences in a natural language (Von Altrock, 1996). Particularly, linguistic preferences are used to evaluate criteria with values that are not numbers but linguistic terms. In practice, linguistic values are commonly represented by a triangular fuzzy number (TFN). This study adopts fuzzy set theory to assess GOP using network QFD; the proposed method is called fuzzy network QFD (FNQFD).

The aim of this study is to employ FNQFD to achieve GOP when measures are interdependent and uncertain. In the case study, four competitive advantages, four enablers and seventeen criteria of GOP are proposed to evaluate a firm in Taiwan. The uncertainty is mainly due to rapid changes in marketing information and human perceptions, while interdependence is mainly found in the measures from GOP evaluation.

CONTRIBUTIONS OF THE STUDY

A first outcome from a literature analysis is that none of the approaches proposed in the literature are grounded on the FNQFD methodology. In practical cases, it would also be possible for an OEM firm to directly identify a set of suitable enablers to be implemented, without linking them with criteria and aligning them with competitive advantages. However, the risk is that the selected strategic leverages do not match marketing objectives (Cil and Evren, 1998). Moreover, QFD allows for identifying network relations and qualitative preferences among enablers and criteria, which are not examined in the methodologies available in the literature.

This study addresses two important and related measures in achieving GOP: The handling of dependence among measures is especially important for qualitative descriptions in nature; qualitative descriptions have to be transformed into a comparable scale. The crisp values must be able to compare the proposed measures and then determine the contribution of the respective measures in OEM firms. In view of the respective advantages of the proposed methods, this study attempts to propose an approach to evaluate GOP. The rationale of the proposed approach is to combine fuzzy set theory with ANP and QFD methods, wherein fuzzy set theory accounts for the linguistic vagueness of qualitative preferences, ANP converts the interdependence relations and QFD translates the voice of customers in the hierarchical structure into intelligible weights (Wu and Lee, 2007; Tseng, 2008; Tseng et al., 2009c).

METHODS

To determine the importance and performance of competitive advantages, enablers and criteria of GOP, the evaluation is structured into a two-stage analysis. The first phase is to define the decision objectives, that is, to evaluate the competitive advantages and enablers in linguistics preferences. The second phase is to analyze the enablers and criteria with the justified weights from the first phase results. However, it is necessary to generate and establish evaluation enablers and criteria based on current scenarios, which is a chain (inter-dependence) of competitive advantages vs. enablers and, enablers vs. criteria. Evaluations are measured by importance and performance scales obtained by; (i) assigning weights to four competitive advantages (CA_i, i = 1,2, , 4) and their associated enablers (EN_i, i = 1,2, , 4) and criteria (C_k i = 1,2, , c_k); and (ii) assessing the importance and performance rating of each competitive advantage and its associated enablers and criteria. This study proposes a fuzzy set theory, ANP and QFD approach, followed by the proposed application procedures.

Fuzzy set theory

This section discusses how linguistic preference is expressed as the importance and performance rating for the evaluation of competitive advantages, GOP enablers, and criteria. A linguistic criterion is hard to express as an exact number, maybe a phrase or sentence expressed in a natural or artificial language. For instance, “very important” is a linguistic description; however, its value is linguistic rather than numerical. Moreover, using approximate reasoning of fuzzy set theory, the linguistic description can be represented with a fuzzy number. This study employs TFNs to represent linguistic preferences to assess GOP enablers and rate the importance of criteria. The triangular membership functions overlap, which represent the different linguistic models depending on the professional evaluator. Each qualitative competitive advantage (CA_i) and criterion (C_k) can be assessed as the degree of importance and as very low (VL), low (L), medium (M), high (H), very high (VH), and the enabler (EN_j) can be assessed as very poor (VP), poor (P), fair (F), good (G), very good (VG).

Two types of linguistic models with TFNs were constructed for fuzzy measures. The assessed values of qualitative criteria metrics are for the importance and performance rating, $\tilde{X}_i = ({}_L x_{ij}, {}_m x_{ij}, {}_R x_{ij})$, i = 1,2,3,4 and j = 1,2,3….., n. This study builds on some important definitions and notations of fuzzy set theory from Chen (1996) and Cheng and Lin (2002). Some definitions are presented thus:

Definition 1: A TFN $\tilde{N}$ can be defined as a triplet (*l, m, u*), and the membership function $\mu_{\tilde{N}}(x)$ is defined as:

$$\mu_{\tilde{N}}(x) \begin{cases} 0, & x \prec l \\ (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & x \succ u \end{cases} \quad (1)$$

where l, m, and u are real numbers and $l \le m \le u$ (Figure 1).

Definition 2: Let $\tilde{N}_1 = (l_1, m_1, u_1)$ and $\tilde{N}_2 = (l_2, m_2, u_2)$ be two TFNs. The multiplication of $\tilde{N}_1$ and $\tilde{N}_2$ is

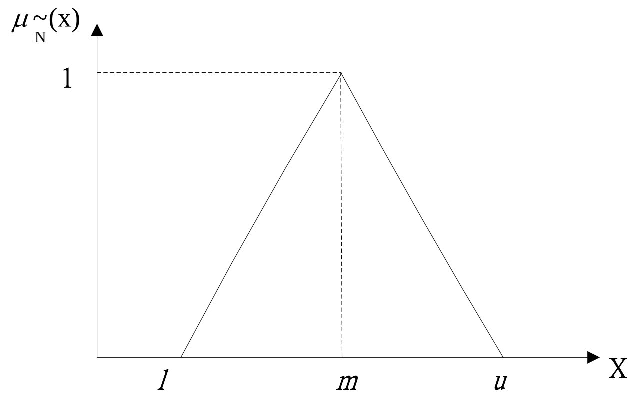

Figure 1. A triangular fuzzy number $\tilde{N}$.

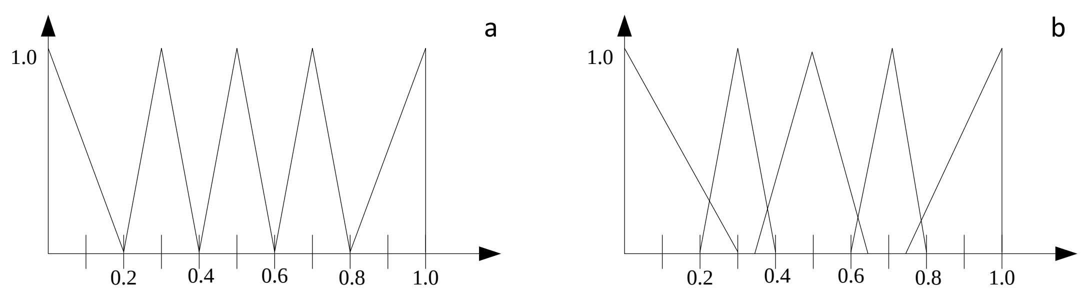

Figure 2. Linguistic models for GOP competitive advantages; (a) Criteria; performance level, (b) Enablers; importance level.

Table 1. Two linguistic models for GOP competitive advantages, enablers and criteria (importance and performance level).

(CA_i) (C_k)	TFNs	(EN_j)	TFNs
VL	(0.00, 0.00, 0.20)	VP	(0.00, 0.00, 0.30)
L	(0.20, 0.30, 0.40)	P	(0.20, 0.30, 0.40)
M	(0.40, 0.50, 0.60)	F	(0.35, 0.50, 0.65)
H	(0.60, 0.70, 0.80)	G	(0.60, 0.70, 0.80)
VH	(0.80, 1.00, 0.00)	VG	(0.75, 1.00, 1.00)

denoted by $\tilde{N}_1 \otimes \tilde{N}_2$. Multiplication of two positive TFNs, $\tilde{N}_1 \otimes \tilde{N}_2$ is approximated as

$$\tilde{N}_1 \otimes \tilde{N}_2 \cong (l_1 \otimes l_2, m_1 \otimes m_2, u_1 \otimes u_2) \quad (2)$$

The measures consist of four competitive advantages, four enablers and seventeen criteria; the measures are determined from extensive literature searches by an expert team. While the triangular fuzzy membership functions (Table 1 and Figure 2) can accommodate the qualitative data, the evaluation process is uncertain.

To deal with the problems in uncertainty, an effective fuzzy aggregation method is required. Any fuzzy aggregation method always needs to contain a defuzzification method because the results of human judgments with fuzzy linguistic variables are fuzzy numbers.

Defuzzification refers to the selection of a specific crisp element based on the output fuzzy set, which converts fuzzy numbers into crisp values. The qualitative measures are based on Dubois and Prade (1980) fuzzy arithmetic, and the calculated aggregation is determined by k evaluators using:

$$\tilde{\bar{X}}_{ij} = ({}_L\bar{x}_{ij}, {}_M\bar{x}_{ij}, {}_R\bar{x}_{ij}) = \left[\left(\sum_{p=1}^{k} x_{ij}^{p} \right) \Big/ k, \left(\sum_{p=1}^{k} x_{ij}^{p} \right) \Big/ k, \left(\sum_{p=1}^{k} x_{ij}^{p} \right) \Big/ k \right] \quad (3)$$

where $\tilde{\bar{X}}_{ij} = ({}_L\bar{x}_{ij}, {}_M\bar{x}_{ij}, {}_R\bar{x}_{ij})$ are the TFNs, and x_{ij} presents at the left, middle and right positions, ${}_L\bar{x}_{ij}, {}_M\bar{x}_{ij}, {}_R\bar{x}_{ij}$, represents the overall average ratings of aspect *i*, criteria *j* over *k* evaluators, and x_{ij}^{p}, p = 1, 2,……*k*, are the fuzzy numbers for each evaluator.

The fuzzy numbers must be transformed into crisp numbers. Many methods can achieve this transformation (for example, means of maxima, center of sum, center of gravity, and the a-cut method). The defuzzification method developed by Chen and Klein (1997) is a very sensitive and effective approach that discriminates between two fuzzy numbers during fuzzy ranking by performing numerous simulated experiments in which various linear or nonlinear fuzzy numbers and various degrees of overlap of fuzzy numbers are applied. The method utilizes fuzzy subtraction of a referential rectangle, $\tilde{Z}$, from a fuzzy number, $\tilde{X}$; the rectangle is obtained by multiplying the height of the membership function of $\tilde{X}$ by the distance between the two crisp maximizing and minimizing barriers. Hence, $\tilde{Z}$ is considered a fuzzy number. Fuzzy subtraction of the referential rectangle, $\tilde{Z}$, from the fuzzy number, $\tilde{X}$, can be performed at level μ_i by the following:

$$\tilde{X}_{\mu i} - \tilde{Z} = [l_i, r_i] - [a_1, a_2] = [l_i - a_2, r_i - a_1]$$
$$i = 0,1,2,\ldots\ldots\ldots\ldots,\infty \quad , \quad (4)$$

where l_i and r_i are the left and right fuzzy numbers of $\tilde{Z}$, and a_1 and a_2 are the left minimum and right maximum fuzzy numbers, respectively.

Defuzzification of a fuzzy number is performed by:

$$D(\tilde{X}) = \sum_{i=0}^{n}(r_i - a_1) \Bigg/ \left(\sum_{i=0}^{n}(r_i - a_1) - \sum_{i=0}^{n}(l_i - a_2) \right) , \quad (5)$$

where n is the number of α-levels, and as n approaches ∞, the summation approaches the area measurement. In Eq. (5), $\sum_{i=0}^{n}(r_i - a_1)$ is positive, $\sum_{i=0}^{n}(l_i - a_2)$ is negative and $0 \le D(\tilde{X}) \le 1$. The minimum values of the left spread and the maximum values of the right spread of the fuzzy numbers are a_1 and a_2, respectively. This proposed framework allows experts to identify options using linguistic expressions. The unique point of this study was involved in qualitative descriptions of linguistic expressions presented by TFNs and defuzzification into a crisp value for analysis by ANP.

ANP approach

ANP is a generalization of the analytical hierarchical process (AHP) (Saaty, 1996). While AHP represents a framework with a unidirectional hierarchical AHP relationship, ANP allows for complex interrelationships among decision levels and criteria. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher, lower, dominant or subordinate. Given the problems encountered in reality, a dependent and feedback relationship is usually generated among the criteria and such interdependence relations usually become more complex with the change in scope and depth of the decision-making problems.

ANP uses a supermatrix to deal with the relations of feedback and dependence among the criteria. If no interdependent relationship exists among the criteria, then the pairwise comparison value would be 0. If an interdependence and feedback relationship exists among the criteria, then such values would no longer be 0, and an unweighted supermatrix M will be obtained. If the matrix does not conform to the principle of column stochasticity, the decision maker can provide the weights to adjust the matrix into a supermatrix that conforms to the principle of column stochasticity, producing a weighted supermatrix M. The limited weighted supermatrix M* is based on Equation (6) and allows for gradual convergence of the interdependence relations to obtain the accurate relative weights among the criteria. The following equations are applied in this study:

$$\text{M*} = \lim_{k \to \infty} M^k \quad (6)$$

In testing for the consistency of a judgment matrix, acceptable matrix results have consistency index (C.I) and consistency ratio (C.R.) values less than 0.1 and the C.I. of a judgment matrix can be obtained by:

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (7)$$

When $\lambda_{max} = 0$, complete consistency exists within judgment procedures. When $\lambda_{max} = n$, the C.R. of C.I. to the mean random consistency index R.I. is expressed as C.R. The equation is as thus:

$$CR = \frac{CI}{RI} \quad (8)$$

ANP is a mathematical theory that can deal with multiple dependencies systematically. The merits of ANP in group decision-making are (Dyer and Forman, 1992; Tseng et al., 2008); (i) both tangibles and intangibles, individual values, and shared values can be included in the decision process; (ii) the discussion in a group can be focused on objectives rather than on alternatives; (iii) the discussion can be structured so that every factor relevant to the decision is considered; and (iv) in a structured analysis, the discussion continues until relevant information from each individual member in the group is considered and a consensus is achieved. However, ANP presents the interdependence relations; this study further analyzes the ANP results using QFD.

QFD approach

QFD is a method that translates customer needs into product technical requirements of new products and services that have been developed in Japan in the late 1960s to early 1970s (Chan and Wu, 2002). The main concept of traditional QFD considered four relationship matrices that included product planning, parts planning, process planning, and production planning matrices (Karsak et al., 2002; Bevilacqua et al., 2006). Each translation used a matrix, which is also called house of quality (HOQ).

To establish these interdependence relations, the business natures are translated into enablers, and controls of the enablers depend on criteria. Several of the critical notions can be expressed thus: competitive advantages. The first step is to identify the “whats”. In sum, there are four enablers for defining the outsourcing performance suggested by Bevilacqua et al. (2006); motives, part characteristics, supplier operating capabilities and supplier relation strategies. GOP guides manufacturing processes toward continuous improvement and sustainable development.

However, interdependence relations exist in the nature of competitive advantages, GOP enablers, and criteria. This study assumes that interdependence relations exist. Therefore, this study employs ANP to represent the interdependence relations between “whats” and “hows”. It is noteworthy that interdependence occurs in all relations. In general, the conventional QFD approach lacks consideration of interdependence. This approach presumes interdependence relations between the “hows”, “whats” and HOQ. The main outputs of this study are obtained from preceding steps of this approach.

Hierarchical structure of GOP

The proposed hierarchical structure is based on an extensive literature review about competitive advantages and synthesis of well-known frameworks for the make-or-buy decision (Venkatesan, 1992; Vining and Globerman, 1999; Canez et al., 2000; Holcomb and Hitt, 2007; Dabhilkar et al., 2009; Tseng et al., 2008; Tseng 2010).

To successfully compete in the marketplace, firms need to offer low-price products (Reed et al., 2000). Lowering cost (CA1) can capture the competitive advantage by measuring the emphasis placed on reducing production costs, reducing inventory, increasing equipment utilization, and increasing capacity utilization. Quality (CA2) is a critical competitive advantage for satisfying customer requirements, and quality of conformance is important to meet product design and operating specifications (Garvin, 1987; Fisher, 1997; Chase et al., 2001; Li et al., 2006). Moreover, delivery reliability (CA3) means that the ability to meet a delivery schedule or promises due to delivery capability is assessed by speed, dependability and production lead time; it also refers to a firm’s ability to supply the product on a promised delivery due date. As mentioned earlier, flexibility (CA4) is a complex and multi-dimensional capability that requires a company-wide effort to increase a firm’s responsiveness and reduce waste and delays. Flexibility is defined as the firm’s ability to provide rapid design change, a wider product range, greater order size flexibility and a greater number of new products (Sethi and Sethi, 1990; Kathuria, 2000; Zhang et al., 2002; Dreyer and Gronhaug, 2004).

Four important enablers emerged from this analysis; competitive advantages, motives for outsourcing (EN1), characteristics of outsourced parts (EN2), supplier operating capabilities (EN3) and supplier relationship strategies (EN4). The literature (Canez et al., 2000; Holcomb and Hitt, 2007; Dabhilkar et al., 2009) argues that motives (E1) have little or even no influence, which usually activate triggers that lead to motives for the make-or-buy analysis. For instance, the price competition in the marketplace triggers firms to reduce costs and motivates outsourcing. Canez et al. (2000) lists a wide range of motives that can be grouped into five distinct subsets; reduce costs (C1); increase focus on industry (C2); increase quality (C3); increase responsiveness (C4); and increase innovation capability (C5).

There are three types of part characteristics in considering the make or buy analysis; volume/degree of

Table 2. Hierarchical structure of GOP.

Goal	CAs	ENs	Cs
Achieving GOP	Competitive advantages - Lowering cost (CA1); Quality (CA2); Delivery reliability (CA3); and Flexibility (CA4)	Motives (E1)	Reduce cost (C1) Focus on industry(C2) Quality (production and service quality) (C3) Responsiveness (customer requirements) (C4) Innovation capability (green or new production development) (C5)
		Part characteristics (E2)	High volume/ standardized parts(C6) Complexity in (green) manufacturing (C7) Complexity in (green) design(C8) Importance to perception of green-product(C9)
		Supplier operating capabilities (E3)	High volumes of outsourced parts(C10) Design of outsourced (green) parts(C11) Purchasing (green)materials of outsourced parts(C12) Operations in low wage countries(C13)
		Supplier relation strategies (E4)	Sharing the production plans and system(C14) Adaptation of production (innovation) processes(C15) Common work for cost reduction(C16) Supplier involvement in new product development (C17)

standardization (C6), complexity, and importance (Vining and Globerman, 1999; Holcomb and Hitt, 2007), with regard to high-volume or standardized parts can be linked to low costs (Vining and Globerman, 1999), outsourcing offers opportunities for lowering costs. Complexity in green manufacturing (C7) and design (C8) is related to technological uncertainty. At increasingly higher levels of uncertainty, this study's emphasis is to reduce cost economies and increase the difficulty of inter-firm collaboration. The customers' perception on green product attributes should be classified as strategic designs (C9). Strategic designs mostly link to taking advantage of the suppliers' higher innovation capability and is often expressed as strategic outsourcing performance (Venkatesan, 1992; Holcomb and Hitt, 2007).

The reviewed GOP indicates that the supplier's operating capabilities are an important enabler to consider in the make-or-buy analysis; the point in outsourcing is to find a partner that complements the capabilities of the firm. The outsourcing suppliers have a distinct comparative advantage such as lower cost structure or stronger performance incentives. The works of Sturgeon (2002) and Tseng (2010) are used to narrow down the capabilities actually contributing to improved performance. Capabilities of performance improvements are identified as volume (C10), design for manufacturing (C11), purchasing scale in green concept (C12) and low-wage operations (C13). Outsourced higher volume parts lead to lower fixed costs, and the supplier should be better able to cope with volume changes for individual customers because demand is aggregated for several customers. However, the purchasing capability for outsourced parts also leads to lower variable costs to get pre-specified components for several customers at lower costs. The operations in low-wage countries lead to lower costs of goods sold that requires labor-intensive or OEM firms. Moreover, the supplier can alter green product design to incorporate cheaper and better components. Standardization of the production processes leads to additional possibilities for continuous improvements.

Sharing of production plans and systems (C14) is related to having a cost focus and is often described as operational collaboration for adaptation of production processes (C15). This collaboration reduces the common work for cost reduction (C16) and allows the firm to receive some benefits as improved pricing and delivery performance through sharing operational schedules and linking forecasting systems. In contrast, these collaboration types are related to having a more differentiated focus on trying to attain superior product functionality and are described as strategic collaborations, which are aimed at competitive advantages from new product development (C17). Thus, to carefully manage resources and capabilities, distinct competence in the marketplace needs to be created (Cousins, 2005; Tseng 2010) (Table 2).

In summary, these criteria are composed for analysis of GOP. There is also strong support from previous studies for assuming that there are dependence relations among the competitive advantages, GOP enablers, and criteria (Leiblein et al., 2002; Tseng and Lin, 2009).

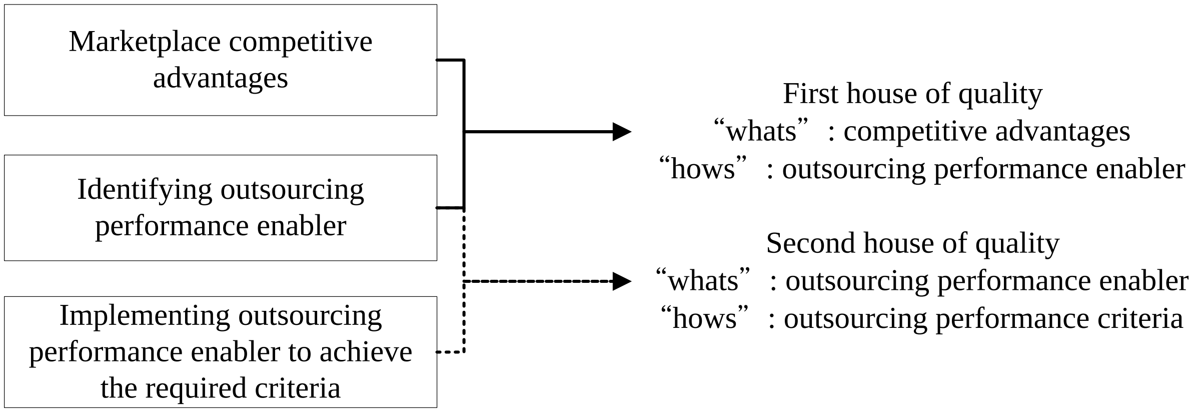

Figure 2. Approach to GOP.

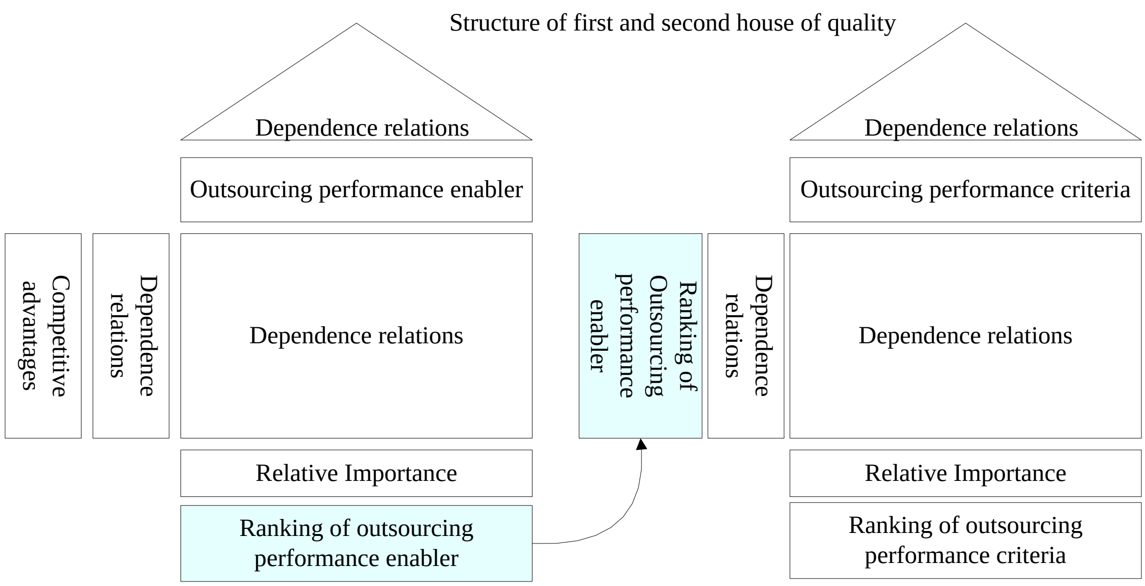

Figure 3. Structure of first and second house of quality.

Proposed approach

In this proposed approach, QFD and HOQ principles are translated from the GOP enablers and criteria. Specifically, this study proposes to exploit HOQ to relate competitive advantages to enablers and criteria. The conceptual model is shown in Figure 2. As seen from the figures, this study requires building an HOQ with the specific structure detailed in Figure 3. Details on how to build the HOQ are provided further. In achieving a favorable solution, the group decision-making process is usually important to any organization. This is because the process of arriving at a consensus should be based upon the reaction of multiple individuals, whereby an acceptable judgment may be obtained.

There are two stages proposed in this study: (1) the competitive advantages tell the company "what to do" in achieving GOP enablers and (2) the enablers are specified as the "hows" of QFD. As a rule of QFD, the enablers indicate the firm's "what to do" and the criteria present "how to do" in achieving GOP.

The first HOQ aims at identifying the relevant competitive advantages (CA_j, j = 1, 2, …n) in achieving GOP that enhance a firm's competitiveness according to a defined set of enablers (EN_i, i = 1.2…..m). Consequently, CAs appear as "whats" in the HOQ, because companies should first identify and rank app-ropriate dimensions to compete, while ENs appear as "hows", because they express attributes to be enhanced depending on the competitive advantages firms are willing to excel in. Nonetheless, as shown earlier, suggestions to identify both ENs and Cs can be found in the literature (Vining and Globerman, 1999; Canez et al., 2000; Holcomb and Hitt, 2007; Dabhilkar et al., 2009), and depending on the specific case study, they may either be considered as exhaustive or different.

Otherwise, additional CAs/ENs and ENs/Cs could be defined and listed in the HOQ as "whats" and "hows".

To achieve GOP and improve the performance of previous methods, this study proposes the following steps for the approach:

1. Gather relevant information from a literature review and expert opinions; it is necessary to consult a group of experts to confirm the reliability of the GOP measures and as mentioned previously, what is necessary to form an expert group for professional and academic knowledge to achieve the evaluation goal.
2. Developing GOP enablers and criteria and survey instrumentation what is important to establish a set of enablers and criteria for evaluation. However, the enablers and criteria have naturally complicated relations within their clusters. To deal with the problem of interdependence, ANP is suitably applied and QFD transfers the customer's voice and competitive advantages to operate in a firm. Moreover, to acquire the responding instrument to ascertain the relationships among the evaluation criteria, it is necessary to consult a group of experts that can confirm reliable information of the influences and directions of the criteria.
3. The crisp value number must be normalized to achieve criteria values that are comparable among all criteria. Interpreting linguistic information into fuzzy linguistic scales can be accomplished using linguistic information to convert fuzzy numbers into crisp values; the fuzzy assessments are defuzzified and aggregated as a crisp value by using the definitions in Equations (1) and (2), and applying Equations (3) to (5).
4. The crisp values are composed into the weight matrices. The interdependence matrices are from ANP using Equations (6) to (8). The crisp value can be composed into a pairwise comparison matrix and the matrix can be decomposed with MATLAB 6.5 to acquire the eigenvector. Moreover, the eigenvector must be normalized into local priority for composing the unweighted supermatrix. In testing for the consistency of a judgment matrix, its consistency index (C.I.) can be obtained using Equation (7). We can acquire the λ_{max} value in the process of decomposing the pairwise comparison matrix. In addition, when $\lambda_{max} = 0$, complete consistency exists within judgment procedures. When $\lambda_{max} = n$, the consistency ratio (C.R.) of C.I. to the mean random consistency index R.I. is expressed as C.R. using Equation (8).
5. The final result can be obtained first from a QFD modeling competitive advantages vs. enablers, and secondly, QFD model is the result of the first QFD model vs. criteria of GOP (Figure 3). The result is obtained by multiplying the matrices to arrive at an overall ranking.

EMPIRICAL STUDY

The aim of this is t to operationalize the evaluation methodology for achieving GOP at a case firm. There are reasons for firms' GOP evaluation. First, the case firm continues to face challenges with how they manage the competitive advantage of GOP enablers. Second, the case firm has to follow the enablers to develop the criteria from a competitive market. In this study, the expert team is formed from two professors, one vice president and five management professionals with extensive consulting experience.

Problem statement

Under the prosperous and booming electronic consumption products and network market, COM Co., LTD is not only the largest professional PCB manufacturer in Taiwan, but it is also ranked as number six worldwide. To offer the best service by an electronic manufacturer, COM Co., LTD is continuing to develop new generation technology, enhancing competitiveness in green perspectives, fully satisfying the market and customer demands and developing a closer relationship with suppliers and customers. COM Co., LTD, insisting on the principle of "highest quality and customer first", have, and continue to spend a lot of effort on improving processes developing GOP and setting the full quality system to meet customer green requirements. Due to electronic product replacement, rapid and new technologies are explored. The capability of developing and researching new technologies is a global competition resource, which meets product demands from customers and explores new products on the market. Therefore, GOP is relatively important for COM to sustain in such a competitive market.

The expert group strived to recommend competitive advantages, enablers, and criteria, and they are expected to remain a long-term competitor in an intensive market. The expert group reviewed the competitive advantages, enablers, and criteria, because GOP is one of the most prioritized issues of the management team. The expert group has a similar need of finding a suitable supplier regarding GOP. It intends to evaluate and select a proper supplier prior to GOP in a more logical and persuasive way as there is a growing need for an analytical and systematic way of solving management decision procedures. For better handling of this problem, the eight experts should adopt possible relative importance criteria. This study would provide criteria ranking, and it would be useful for efficient and effective GOP achievement.

The results

This study follows the five steps of the proposed fuzzy QFD approach to measure the data from the experts. The proposed solution is with five-phase procedures as listed thus:

Table 3. Example of TFNs in competitive advantages.

CA 1	CA 1	CA 2	CA 3	CA4
CA 1	1.00	(0.40, 0.50, 0.60)	(0.80, 1.00, 1.00)	(0.60, 0.70, 0.80)
CA 2	(1.67, 2.00, 2.50)	1.00	(0.40 0.50 0.60)	(0.60, 0.70, 0.80)
CA 3	(1.00, 1.00, 1.25)	(1.67, 2.00, 2.50)	1.00	(0.20, 0.30, 0.40)
CA 4	(1.25, 1.43, 1.67)	(1.67, 2.00, 2.50)	(2.50, 3.33, 5.00)	1.00

Table 4. Defuzzification and eigenvector.

CA 1	CA 1	CA 2	CA 3	CA 4	E-vector	Weights
CA 1	1.00	0.13	6.92	0.17	0.48	0.24
CA 2	8.00	1.00	0.35	0.94	0.55	0.28
CA 3	0.14	2.83	1.00	5.99	0.53	0.27
CA 4	5.92	1.07	0.17	1.00	0.44	0.22

Table 5. Unweighted super matrix of competitive advantages.

Weights	CA 1	CA 2	CA 3	CA 4
CA 1	0.24	0.31	0.37	0.27
CA 2	0.28	0.21	0.15	0.23
CA 3	0.27	0.29	0.29	0.22
CA 4	0.22	0.19	0.19	0.28

1. The evaluation goal is to identify significant decision-making criteria and form an expert group with professional and academic knowledge to evaluate the competitive advantages, enablers and criteria of GOP.
2. The evaluation pairwise comparison questionnaire is with a set of competitive advantages, enablers and criteria for experts' evaluation. The professional experts have over ten years of experience in the case firm. However, the group of experts is necessary to confirm that the competitive advantages, enablers and criteria, are reliable. This study follows the nature of all measures with interdependence relations; ANP is proposed to deal with this particular issue. These experts were requested to complete a survey using subjective judgment for the importance of each criterion for the hierarchical structure of the study's framework.
3. However, the qualitative measures are always subjective with linguistic preferences. Therefore, the measures have to be based on the TFNs to transform the linguistic preferences into comparable crisp scores; examples of TFNs are presented in Table 3. Interpreting the linguistic information into a fuzzy linguistic scale (Table 2) is by conversion of fuzzy numbers into crisp values by applying Equations (3) to (5) to defuzzify and aggregate the crisp values. A crisp value must be normalized to achieve criteria values that are comparable among all criteria. The weights of competitive advantages are 0.24, 0.28, 0.27, and 0.22 (Table 4).
4. The interdependence matrices are from ANP using Equations (6) to (8). The crisp values can compose a pairwise comparison matrix, and decomposition of the matrix can be performed by MATLAB 6.5 to acquire the eigenvector. The eigenvector must be normalized into weights for composing the unweighted supermatrix. In testing for the consistency of the judgment matrix, C.I. is 0.075. If the C.I. ratio is greater than 10%, we need to revise the subjective judgment. The C.R. resulted in 0.085, which is also lower than 0.1. The unweighted supermatrix of competitive advantages is presented. The weights of each competitive advantage are the following; competitive advantage's weights in CA 2 are 0.31, 0.21, 0.29 and 0.19; the weights in CA 3 are 0.37, 0.15, 0.29 and 0.19; and the weights in CA 4 are 0.27, 0.23, 0.22 and 0.28, as shown in Table 5. Lastly, the ranking of the converged competitive advantage matrix from Table 5 is CA1 (0.296) > CA3 (0.267) > CA4 (0.219)> CA2 (0.218).

Repeating step 4, the weights of each enabler are the following; the enabler's weights in EN1 are 0.40, 0.50, 0.04 and 0.06; the weights in EN2 are 0.23, 0.21, 0.29 and 0.27; the weights in EN3 are 0.32, 0.21, 0.28 and 0.19; and the weights in EN4 are 0.37, 0.23, 0.12 and 0.28. The ranking of the converged enablers matrix is EN1 (0.327) > EN2 (0.309) > EN (0.189) > EN3 (0.175).

Table 6 presents the unweighted supermatrix for each criterion. Defuzzification is computed seventeen times to acquire the E-vector and normalize by the weights. For

Table 6. Unweighted super matrix of criteria.

Weights	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C1	0.0006	0.085	0.075	0.074	0.065	0.057	0.068	0.057	0.062	0.095	0.360	0.068	0.052	0.075	0.085	0.098	0.055
C2	0.0005	0.062	0.045	0.063	0.052	0.052	0.056	0.052	0.053	0.052	0.044	0.038	0.052	0.080	0.070	0.052	0.052
C3	0.0007	0.039	0.062	0.039	0.085	0.063	0.085	0.039	0.039	0.062	0.039	0.039	0.049	0.062	0.062	0.062	0.062
C4	0.0016	0.052	0.041	0.040	0.060	0.086	0.038	0.085	0.040	0.041	0.039	0.040	0.085	0.041	0.041	0.041	0.090
C5	0.0018	0.023	0.044	0.085	0.085	0.056	0.090	0.076	0.038	0.044	0.038	0.012	0.041	0.044	0.044	0.044	0.044
C6	0.0024	0.034	0.042	0.078	0.041	0.058	0.042	0.065	0.039	0.042	0.041	0.150	0.068	0.042	0.042	0.042	0.042
C7	0.0050	0.039	0.070	0.050	0.075	0.041	0.041	0.058	0.042	0.039	0.041	0.042	0.068	0.039	0.039	0.039	0.039
C8	0.0054	0.050	0.044	0.039	0.069	0.080	0.043	0.061	0.042	0.044	0.039	0.078	0.060	0.044	0.044	0.044	0.044
C9	0.0083	0.096	0.096	0.040	0.040	0.041	0.086	0.056	0.041	0.096	0.041	0.044	0.085	0.096	0.096	0.096	0.096
C10	0.0146	0.060	0.060	0.041	0.040	0.040	0.039	0.075	0.065	0.060	0.040	0.063	0.040	0.060	0.060	0.060	0.060
C11	0.0267	0.052	0.052	0.037	0.037	0.091	0.056	0.052	0.037	0.052	0.037	0.085	0.062	0.052	0.052	0.052	0.052
C12	0.0331	0.056	0.056	0.041	0.085	0.040	0.041	0.086	0.041	0.056	0.041	0.061	0.085	0.056	0.056	0.056	0.056
C13	0.0365	0.062	0.062	0.085	0.072	0.041	0.081	0.086	0.098	0.062	0.040	0.085	0.039	0.062	0.062	0.062	0.062
C14	0.0833	0.035	0.020	0.075	0.057	0.039	0.040	0.041	0.150	0.020	0.040	0.080	0.041	0.020	0.020	0.020	0.020
C15	0.2300	0.085	0.095	0.063	0.053	0.035	0.075	0.035	0.085	0.095	0.034	0.035	0.035	0.095	0.095	0.095	0.095
C16	0.1692	0.084	0.084	0.095	0.040	0.100	0.062	0.040	0.068	0.084	0.040	0.039	0.055	0.084	0.084	0.084	0.084
C17	0.3803	0.090	0.052	0.058	0.041	0.085	0.059	0.040	0.060	0.052	0.040	0.040	0.085	0.052	0.052	0.052	0.052

example, the weights from C1 to C17 in C1 are 0.0006, 0.0005, 0.0007, 0.0016, 0.0018, 0.0024, 0.0050, 0.0054, 0.0083, 0.0146, 0.0267, 0.0331, 0.0365, 0.0833, 0.2300, 0.1692, and 0.3803.

5. The final result can be obtained from the first QFD modeling competitive advantages vs. enablers. Table 7 presents the HOQ in CAs and ENs. The second QFD model is the result of the first QFD model vs. the criteria of GOP. The result is obtained from the multiplied matrix to arrive at the overall ranking. Table 8 presents the converged supermatrix HOQ of ENs and Cs. The several ANP interdependence matrix results are used to compose the unweighted supermatrix. The supermatrix is a partitioned matrix, where each sub matrix is composed of a set of relations of feedback or dependency.

Table 9 shows the relative importance and final ranking. The ranking of criteria is as follows: C16(0.0637) > C15(0.0629) > C2(0.0616) > C7(0.0611) > C17(0.0606) > C11(0.0602) > C12(0.0598) > C4(0.0597) > C9(0.0595) > C14(0.0592) > C10(0.0602) > C1(0.0564) > C5(0.0552) > C8(0.0552) > C3(0.0550) > C13(0.0535). To assess the evaluation in an effective way, several managerial implications can be derived from the results.

MANAGERIAL IMPLICATIONS

To assess the evaluation in an effective way, the valuable cues can be drawn from the relative importance (Table 9) and the final ranking. The GOP framework is used to evaluate the impact at various activities and thus provides a mechanism to monitor and establish a measurement platform for the firms. Although in previous studies there was a great deal of variation in this measurement, this variation did not generally appear to have a clear link to these organizational decision contexts. Indeed, in regards to the prior study that only stressed a single variable and the rapidly changing challenge for the business environment, a single model or variable was not good enough for evaluation. Because GOP is multi-hierarchical in nature, measures of concepts and single models cannot be good enough for evaluation. In particular, when evaluating the impact of introducing developed GOP, activities need to form the overall competitive advantages and

Table 7. HOQ of competitive advantages and enablers.

	EN 1	EN 2	EN 3	EN 4
CA 1	0.268	0.157	0.196	0.356
CA 2	0.315	0.516	0.210	0.256
CA 3	0.296	0.125	0.186	0.178
CA 4	0.121	0.202	0.408	0.210

Table 8. Converged HOQ of enablers and criteria.

	C1	C	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
EN 1	0.24	0.27	0.24	0.26	0.24	0.26	0.26	0.24	0.26	0.25	0.26	0.26	0.23	0.26	0.27	0.28	0.26
EN 2	0.24	0.27	0.24	0.26	0.24	0.26	0.26	0.24	0.26	0.25	0.26	0.26	0.23	0.26	0.27	0.28	0.26
EN 3	0.24	0.27	0.24	0.26	0.24	0.26	0.26	0.24	0.26	0.25	0.26	0.26	0.23	0.26	0.27	0.28	0.26
EN 4	0.24	0.27	0.24	0.26	0.24	0.26	0.26	0.24	0.26	0.25	0.26	0.26	0.23	0.26	0.27	0.28	0.26

consider its effect on the organization contextual. The proposed framework can provide managers and researchers better understanding of the differences in management activity needs and specific management interventions that would improve the likelihood of excellent and useful research by examining the seventeen criteria of this approach. These criteria serve as bridging mechanisms that help with GOP for a firm. The proposed framework also provides the function of management control and track, further helping to describe the dilemmas. For example, the converged weights of four competitive advantages are described. Here, the values of lowering cost, quality, delivery reliability, and flexibility are 0.296, 0.218, 0.267, and 0.219, respectively. The converged weights of the enabler for motive, parts characteristics, supplier operating capabilities, and supplier relation strategies are 0.327, 0.309, 0.175, and 0.189, respectively. Table 9 represents the overall relative importance value of the evaluators' perception of the criteria perspective. The top 10 ranking criteria are; 1) common work for cost reduction (C16); 2) adaptation of production (innovation) processes (C15); 3) quality (production and service quality) (C3); 4) complexity in (green) manufacturing (C7); 5) supplier involvement in new product development (C17); 6) design of outsourced (green) parts (C11); 7) purchasing (green) materials for outsourced parts (C12); 8) responsiveness (customer requirements) (C4); 9) importance to perception of green-product (C9); and 10) sharing the production plans and system (C14). Furthermore, in lowering cost, management must be tracked back for improvement of the motive enablers in the criteria of common work for cost reduction. In other words, the motive is most important when aligned with a specific competitive advantage. Similarly, the common work for cost reduction is also tracked back and upon inspecting their production process, the decision department is asked to improve them. Therefore, the adaptation of production (innovation) processes shows the second weighted criteria. Throughout analyzing all sets of measures by experts, lowered cost is determined by the OEM firm's management, which is meaningful to their cost structure. In the broader sense, the proposed framework can be used as an analytical monitoring tool to develop and construct the overall strategic GOP of the case firm. For the practice of management, the framework is sufficient for organizational managers to greatly understand GOP as an interrelated combination of the enablers and criteria in alignment with competitive advantages. Through the framework, the managers are able to capture a fairly complete picture of GOP contextually. In other words, managers may find that application of the framework for assessing the relative performance of the criteria of the proposed framework developed, validated and operationalized in their daily operations and management activities is a useful decision-making framework for reviewing and improving GOP evaluation and strategic development, which may lead to enhancing performance and sustaining a competitive advantage.

In addition, this study has several implications for firms that intend to evaluate OEM firms in terms of GOP. The main contribution of the paper is the hierarchical and feedback model using the ANP approach. This model provides a useful guideline as a structured and logical means of synthesizing judgments for evaluating appropriate GOP criteria for an OEM firm. It helps structure a difficult and often emotion-burdened decision. The second implication is the enablers listed in the proposed model. Based on a comprehensive review, the features of enablers have been examined and identified. These give an overview structure for the case firms without much knowledge of GOP. Such firms can better understand the evaluation criteria in terms of the competitive advantages and enablers in achieving GOP. The ANP methodology is particularly useful for decision

Table 9. Result

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
R.I.	0.0819	0.0895	0.0798	0.0868	0.0802	0.0860	0.0887	0.0801	0.0864	0.0832	0.0875	0.0869	0.0777	0.0860	0.0914	0.0926	0.0881
Weights	0.0564	0.0616	0.0550	0.0597	0.0552	0.0592	0.0611	0.0552	0.0595	0.0573	0.0602	0.0598	0.0535	0.0592	0.0629	0.0637	0.0606
Ranking	12	3	14	8	13	10	4	13	9	11	6	7	15	10	2	1	5

making in a multi-criteria, interdependence context.

Moreover, the proposed framework may also have an advantage in customizability as other OEM firm's management can take the framework and modify it for use in their own GOP activities. In this manner, evaluators need to take the GOP and delete their relevant criteria from it and add what is missing. Consequently, GOP can be used with different enablers/criteria or aligned with a specific competitive advantage and can be further modified and refined if required.

Concluding remarks

The studies competitive advantages, enablers and criteria, serve as bridging mechanisms that are helpful in achieving GOP. The literature has contributed to identifying the measures influencing the evaluation of a specific case firm. The main contributions of this study are twofold. First, evaluation can be considered as a complex, interdependent and uncertain decision-making problem. This study conducts a review of the literature to generate seventeen criteria along with four enablers to measure the GOP.

Second, this study integrates TFNs, ANP and QFD to develop a FNQFD evaluation model that prioritized the relative weights of measures. The proposed method can be used not only as a way to handle the interdependence within a set of measures but also as a way of producing more valuable information to acquire the measures' ranking for decision-making of GOP evaluation. The study findings indicated that there are solid results with regard to the proposed evaluation. Analysis of these results provides guidance to a firm's management in identifying the key criteria facilitating GOP evaluation and finds the best direction for improving a firm's GOP currently.

From a firm's management perspective, the findings provide suggestions to the case firm. First, because common work for cost reduction generally considers most weight on the case firm, enhanced daily operations can help reduce and figure out their cost structure by enhancing the adaptation of production (innovation) processes and reducing common works in operation. In terms of GOP, the management should actively focus on industry to satisfy the customer needs, and the complexity in (green) manufacturing should promptly and accurately present satisfying contents and subjects, while also being sufficient to help management enhance their internal operations. Second, to cater the supplier involvement in new product development, the internal process design should provide an effective process with shorter waiting time in internal operation aspects. Management should improve the internal information system to provide effective new product information in supplier points of view.

There are several limitations to this study, requiring further examination and additional research. First, this study was conducted with relatively expert group samples. A larger sample that brings more explanatory power would have allowed for a more sophisticated evaluation analysis. The study findings should be verified with a larger sample to increase generalizability. Second, this study uses FNQFD to develop an evaluation model that helps management understand the critical criteria in implementing GOP evaluation. Future studies can adopt additional fuzzy multi-criteria approaches (such as TOPSIS, VIKOR and DEMATEL) to estimate the relative weights of the influences on proposed evaluation. The results of future studies can then be compared with the results presented here. Third, the evaluation criteria were selected from a review of the literature on this approach, an intensive review that excluded some possible influences in achieving GOP evaluation.

Future studies can use different methodologies, such as longitudinal studies and interviews to identify other criteria. Finally, to provide more objective information on applicability of the proposed FNQFD evaluation model, future studies need to be undertaken using case studies of particular GOP evaluation, thus proving the practicality of the FNQFD evaluation procedure proposed by this study. In addition, this study provides a valuable reference for OEM firms concerned with GOP. Results of this study significantly contribute to the efforts in evaluating whether the firm complies with potential customer/supplier requirements based on their capabilities.

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