國 立 交 通 大 學

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博士論文

運用多目標決策方法評選供應鏈組成夥伴

Using Multiple Criteria Decision-Making Method for Partners Selection in Supply Chain

研 究 生： 韓慧林

指導教授： 劉復華 博士

中 華 民 國 九 十 五 年 元 月 十 六 日

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摘　要

供應鏈組成夥伴評選之議題廣受注目，然選擇對的供應鏈組成夥伴，對高階管理者言，是一項艱難的任務。因為供應鏈組成夥伴之選擇並不是獨立的，乃與其他成員間之互動息息相關，深受決策模式之影響。本論文探討兩個不同選擇供應鏈上供應商之議題

第一個議題，運用層級分析法 (AHP) 進行供應商評選作業。我們以投票式排序評選模式，即所謂投票式層級分析法 (VAHP) 以取代既有 AHP 成對比較的方法。此投票式層級分析法區分三個步驟，首先，由每一位決策者針對受評估目標進行排序，以避免兩兩比較方法的不一致性問題；其次，運用線性規劃模式求出排序之權重值；再其次，計算出受評估目標的總得分數，以排列優先順序。

第二個議題，運用多目標二元整數規劃模式，以個別受評單元進行組合評估方式，評選不同組合之供應商。在假設有 K 個供應商時，則有 2^K 個不同之受評供應商組合，並應用成本、交期、彈性與品質等四項績效衡量指標，結合資料包絡法 (DEA)，進行多元組合供應商評選。最後，針對落在高效外廓之受評單元，實施敏感度分析。

關鍵詞：資料包絡法、多目標二元整數規劃、多目標決策

Using Multiple Criteria Decision-Making Method for Partners Selection in Supply Chain

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ABSTRACT

The issue of supplier selection catches many attentions in supply chain management. The suppliers of the supply chain operate interactively rather than independently, as the output of one organization could be the input of another organization. In this dissertation, we are dealing with two issues of supplier selection in supply chain.

The first issue is that a group of decision-makers to rank a set candidates of suppliers. We employ Analytic Hierarchy Process (AHP) for supplier selection. The pair-wise comparison method proposed by Saaty in AHP is substituted by a voting method. The voting method contains three steps. In the first step, each decision-maker ranks the alternatives to avoid the inconsistency that usually appeared in pair-wise comparison method. The second step is to summarize the votes each alternative earned in every rank. The third step is using a linear programming model to determine the weights assigned to every votes in those ranks. Then, the score of each alternative earned is the sum of weighted votes and gets priority of alternatives.

The second issue is to select a set of multiple suppliers. There are 2^K possible sets of multiple suppliers under selection if there are K supplier candidates. Cost, delivery, flexibility and quality are the four indices used to measure the suppliers' performance. These four indices are also used to measure the performance of the possible sets under selection. The value of each index of a set is equal to the sum of values of the suppliers in it. We employ data envelopment analysis (DEA) to measure the relative performance of each set of multiple suppliers against the 2^K possible sets with the four indices. Then, we perform sensitivity analysis on each index of candidates and provide different strategies in order to select various suppliers of a supply chain for customers.

Keywords：Data Envelopment Analysis (DEA), Multiple Objectives Binary Integer Linear Programming (MOBILP), Multiple Criteria Decision-Making (MCDM)

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韓慧林　謹誌於

國立交通大學工業工程與管理學系

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Hui-Lin Hai

CONTENTS

FIGURE CAPTIONS

TABLE CAPTIONS

NOTATIONS

MOBILP

K : the total number of activities.

m : the total number of resources.

s : the total number of products.

a_{ik} : the amounts of resource i consumed by activity k, i =1, … , m, and k =1, … , K.

c_{rk} : the amounts of product r produced by activity k, r =1, … , s, and k =1, … , K.

x'_i : the objective function value of input i.

y'_r : the objective function value of output r.

w_k : binary variable; w_k=1 if k^{th} activity is performed and w_k=0 otherwise, k =1, … , K.

$\mathbf{A}$: the $m \times K$ matrix of the m input value for the K activities.

$\mathbf{C}$: the $s \times K$ matrix of the s output value for the K activities.

$\mathbf{\Omega}$: the set of all possible DCUs.

$\mathbf{\Omega}_D$: the set of DMUs that corresponding to DCUs in $\mathbf{\Omega}$.

DEA

DMU_o : subscript "o" refers to the DMU currently under evaluation.

n : the total number of DMUs.

j : the index for DMUs, j =1, … , n.

i : the index for inputs, i =1, … , m.

r : the index for outputs, r =1, … , s.

x_{ij} : the units of input i consumed by DMU_j, i = 1, … , m; j = 1, … , n.

y_{rj} : the units of output r produced by DMU_j, r = 1, … , s; j = 1, … , n.

x_{io} : the units of input i consumed by DMU_o (being evaluated), i = 1, … , m.

y_{ro} : the units of output r produced by DMU_o (being evaluated), r = 1, … , s.

x'_{io} : the units of input i consumed by DMU_o (for efficient DMUs), i = 1, … , m.

y'_{ro} : the units of output r produced by DMU_o (for efficient DMUs) , r = 1, … , s.

μ_r : the weight assigned to output r, r =1, … , s.

v_i : the weight assigned to input i, i =1, … , m.

λ_j : the variable for projecting DMU_j, j =1, … , n.

s_r^+ : the slack in the amount of output r, r =1, … , s.

s_i^- : the slack in the amount of input i, i =1, … , m.

ε : the non-Archimedean (infinitesimal) constant.

u_0 : the intercept variable that reflect the impact of scale size of a DMU.

ρ : the scalar number of input variable, $\rho \geq 1$.

ϖ : the scalar number of output variable, $0 < \varpi \leq 1$.

θ, T, T', Z, Z', W, W': the objective values.

δ, π, ψ, ϕ: the scalar variables.

θ^*, δ^*, and π^* : the optimal values of θ, δ, and π, respectively.

Vote-ranking method

g : the number of voters.

e : the number of places, e =1, … , E.

l : the number of criteria, l =1, … , L.

u_{le} : the weights of the e^{th} place with respect to the l^{th} criterion.

x_{le} : the total votes of the l^{th} criterion for the e^{th} place by g voters.

θ_{ll} : the objective value.

$d(e, \varepsilon)$: the difference in weights between e^{th} place and $(e+1)^{th}$ place.

Criteria index

D_j : the planned delivery time for supplier j, j =1, … , n.

d_j : the actual delivery time for supplier j, j =1, … , n.

$C(D_j)$: the penalty function of delivery time for supplier j, j =1, … , n.

Q_j : the standard quality level for supplier j, j =1, … , n.

q_j : the actual quality level for supplier j, j =1, … , n.

$C(Q_j)$: the penalty function of quality for supplier j, j =1, … , n.

f_j : the average scores of flexibility for supplier j, j =1, … , n.

c_j : the average cost for supplier j, j =1, … , n.

α, β, γ : the constants.

1. INTRODUCTION

1.1 Introduction of Supply Chain

Under the high competitive and interrelated manufacturing environment of nowadays, an effective supplier selection process is very important for the success of any manufacturing organization. The emergence of a global competitive environment not only requires better use of supply chain (SC) resources to coordinate geographically dispersed manufacturing process and marketing activities but also has created a situation in which SC efficiency and effectiveness are critical to success. The suppliers of the supply chain perform interactively rather than independently, as the output of one organization could be the input of another organization. Selecting the right supplier is always a difficult task for top managers. Every decision needs to be affirmative and integrated by trading off performances of suppliers at each supply chain stage.

Fierce competition in today's global markets, the introduction of products with short life cycles and the heightened expectations of customers have forced business enterprises to invest in and focus attention on their supply chains. In a typical supply, raw material is procured, items are produced in one or more factories, shipped to warehouse for intermediate storage, and then shipped to retailers or customers. The supply chain definition used in this research focus issue follows the spirit of the value chain concept: (Mabert & Venkataramanan, 1998)

> *Supply chain is the network of facilities and activities that performs the functions of product development, procurement of material from suppliers, the movement of materials between facilities, the manufacturing of products, the distribution of finished goods to customers and after-market support for sustainability.*

In order to survive and prosper, the companies should operate their supply chains as extended enterprises with relationship, which embrace business processes, from material extraction to consumption. The emergence of a global competitive environment not only has required better use of SC resources to coordinate geographically dispersed manufacturing and marketing activities but also has created a situation in which SC efficiency and effectiveness are critical to success. It depicts a simplified supply chain network structure, the information and product flows and the key supply chain business processes penetrating functional silos within the company and various corporate silos across the supply chain in the Figure 1-1.

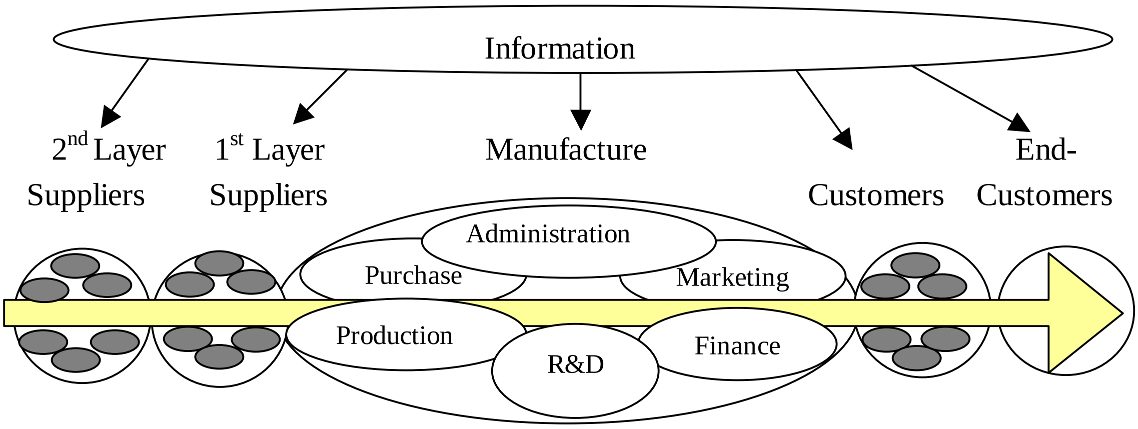

Figure 1-1: Supply chain management

As this happens, supply chain takes on increased importance within the firm since costs, especially transportation, become a larger portion of the total cost structure. For example, if a firm seeks foreign suppliers for the materials entering its product or foreign locations to build its products, the motivation is to increase profit. A single firm is not generally able to control its entire product flow channel from the source of raw material to the points of final consumption. Therefore, ranking and selecting the right suppliers to organize a supply chain is very important but difficult tasks for managers. These issues are 1) the members of the supply chain, 2) the structural dimensions of the network, and 3) the different types of process links across the supply chain. Therefore, we will raise the following research topics when we construct the supply chain networks:

(1) Supply Chain Network Structure: which of them are the key supply chain members with the link processes?

(2) Supply Chain Business Process: what processes should be linked with these key supply chain members?

(3) Supply Chain Management Components: what level of integration should be applied for each process link?

1.2 Problem Definition

In this dissertation, we are dealing with two issues of supplier selection in supply chain systems. The first issue is a group of decision-makers to rank the supplier candidates. We employ Analytic Hierarchy Process (AHP) for supplier selection. The pair-wise comparison method proposed by Saaty (1980) in AHP is substituted by a voting method. The voting method contains three steps. In the first step, each decision-maker ranks the alternatives to avoid the inconsistency that usually appeared in pair-wise comparison method. The second step is to summarize the votes each alternative earned in every rank. The third step is using a linear programming model to determine the weights assigned to every votes in those ranks. Then, the score each alternative earned is the sum of weighted votes.

The second issue is to select a set of multiple suppliers. There are 2^K possible sets of multiple suppliers under selection if there are K supplier candidates. Cost, delivery, flexibility and quality are the four indices used to measure the suppliers' performance. These four indices are also used to measure the performance of the possible sets under selection. The value of each index of a set is equal to the sum of values of the suppliers in it. We employ data envelopment analysis (DEA) to measure the relative performance of each set of multiple suppliers against the 2^K possible sets with the four indices. Then, we perform sensitivity analysis on each index of candidates and provide different strategies in order to select various suppliers of a supply chain for customers.

1.3 Dissertation Organization

Section two reviews the related literatures in supplier selection in supply chain, Multiple Criteria Decision-Making (MCDM), Multiple Objectives Binary Integer Linear Programming (MOBILP) and DEA. Section three presents the method to deal with the first issue. Section four illustrates the procedure for solving the addressed second issue. The structure of this study is illustrated in Figure 1-2.

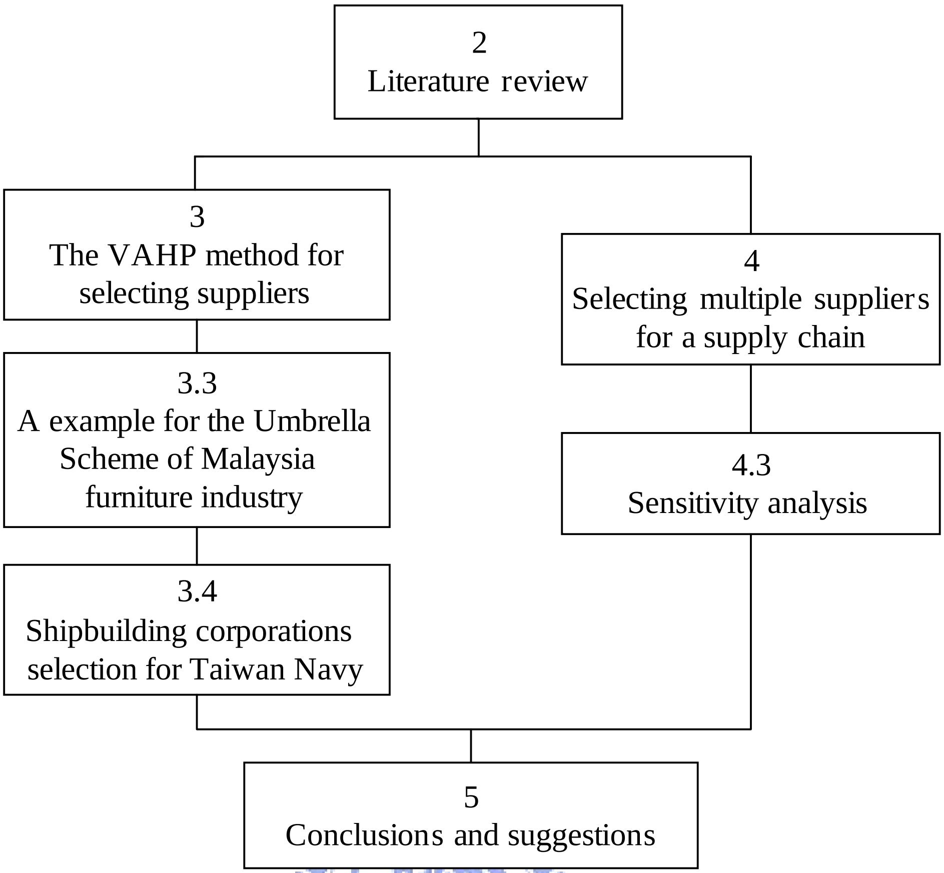

Figure 1-2: Dissertation organization

2. LITERATURE REVIEW

2.1 Supplier Selection in Supply Chain

One major aspect of the purchasing function is the selection of supplier, which includes the acquisition of required material, services and equipment for all types of business enterprises. The first step in any supplier rating procedure is to establish criteria for supplier selection. Weber et al. (1991, 1993) review and classify various articles related to the selection of supplier and discusse the impact of just-in-time (JIT) manufacturing strategy on supplier selection. They use Dickson's 23 criteria and indicate that net price, delivery and quality are discussed in 80%, 59% and 54% of the 74 articles respectively. Identifying these capabilities is difficult because many different criteria are involved of being good supplier, trust and coordination play a major role are very important in achieving price reductions, quality improvement, reduced production development time and flexibility (Maloni & Benton 1997; Monczka et al., 1998).

Fawcett et al. (1997) represent a measure of the firm's logistics performance concerning key factors such as cost, quality, delivery, flexibility and innovation. This is not an easy decision because there are many different criteria for a good supplier. The criteria to develop a partnership with a supply chain member organization are typically driven by the expectation of cost efficiency, delivery dependability, volume flexibility, information, quality and customer service (Choi et al., 1996; Motwani et al., 1998; Olhager & Selldin, 2004). Different companies have different specific requirements concerning supplier evaluation. For instance, in the automotive industry (Europe), functions of supplier logistics performance measurement include strategy formulation and clarification, management information, communication, motivation of suppliers, coordination and alignment (Schmitz & Platts, 2004). Different companies have different specific requirements concerning supplier evaluation. In Consumer Electronics Division of Philips Electronics Industries (Taiwan) Limited requirements for supplier selection include cost, delivery, flexibility, quality and response (Li et al., 1997).

Prahinski and Benton (2004) use structural equation modeling and collect data from 139 first-tier North American automotive suppliers. They indicate that when a purchaser utilizes collaborative communication, the supplier perceives a positive influence on the buy-supplier relationship. Hai (2004) adopts DEA model to evaluate the operational efficiency of the top 57 semi-conduction companies in Taiwan and uses sensitivity analysis to examine the range of reliability of the best-practice frontier. Liu and Hai (2006a) use DEA to measure the efficiency of the possible suppliers. Each supplier is evaluated in four indices: cost, delivery, flexibility and quality. The problem is modeled as a MOBILP. We perform sensitivity analysis through perturbing the evaluation indices of each supplier. Narasimhan et al. (2001) propose a methodology for effective supplier performance evaluation based on DEA, a multi-factor productivity analysis technique. This article aids in supplier process improvement, which in turn enhances firm performance, allows for optimal allocation of resources for supplier development programs, and assists managers in restructuring their supply chain network (Ross & Droge, 2004).

Some authors apply an Activity Based Costing (ABC) approach for supplier selection. Management experts consider the economic aspects of supplier evaluation, and focus on the direct costs (price) and indirect costs (quality) of materials supplied by suppliers (Tagaras & Lee, 1996). However, since suppliers in a supply chain perform interactively, some cost-based mathematical models in the literature appear insufficient for delineating such key supply chain characteristics as multiple objectives and responsive requirements (Schneeweiss, 1998; Li & O'Brien, 1999).

Dickson (1996) identifies 23 different criteria evaluated in the supplier selection process listed in Table 2-1. In that article, quality is treated as being of extreme importance while delivery, performance history, warranties and claim policies, production facilities and capacity, price, technical capability and financial position were viewed as being of considerable importance in the supplier selection process. Yahya and Kingsman (1999) operate the particular Umbrella Scheme of Malaysia's furniture industry and use the criteria of supplier selection in Dickson's research. A major part of the scheme is that all wooden furniture specified what kinds of requirements for government department and services, including school, administration, police, hospitals and military etc., are bought only from supplier companies that are members of the scheme.

Table 2-1: The different criteria evaluated in the supplier selection process

Criteria	Dickson's Study [a]		1991 Exercise	No. of Articles [b]
	Ranks	Evaluations	Ranks	
Quality	1	EI	1	40
Delivery	2	CI	4	44
Performance history	3	CI	2	7
Warranties and claim polices	4	CI	4	0
Production facilities / capacity	5	CI	6	23
Price	6	CI	3	61
Technical capability	7	CI	10	15
Financial position	8	CI	8	7
Bidding procedural compliance	9	AI	8	2
Communication system	10	AI	n.a.	2
Industry reputation and position	11	AI	10	8
Desire for business	12	AI	7	1
Management and organization	13	AI	12	10
Operation controls	14	AI	14	3
Repair service	15	AI	15	7
Attitude	16	AI	n.a.	6
Impression	17	AI	17	2
Packaging ability	18	AI	n.a.	3
Labor relations record	19	AI	18	2
Geographical location	20	AI	16	16
Amount of past business	21	AI	13	1
Training aids	22	AI	n.a.	2
Reciprocal arrangement	23	SI	n.a.	2

[a] EI= extreme important, CI= considerable important, AI= average important, SI= slight important.
[b] No. of article in Weber, Current and Benton 1991 review of 74 papers.
* Source: Yahya and Kingsman (1999).

The relationships with suppliers are different. They seem to work best when they are more family-like and less rational. Relationships with full commitment on all sides endure long enough to create value for the suppliers. In fact, the best organizational relationships, like the best marriage, are true partnerships that tend to meet certain criteria (Kanter, 1994):

Individual Excellence: Both partners are strong and have something of value to contribute to the relationship. Their motives for entering into the relationship are positive.

Important: The relationship fits major strategic objectives of the partners, so they want to make it work. Partners have long-term goals in which the relationship plays a key role.

Interdependence: The partners need each other. They have complementary assets and skills. Neither can accomplish alone what both can together.

Investment: The partners invest to each other to demonstrate their respective stake in the relationship of each other. They show tangible signs of long-term commitment by devoting financial and other resources to the relationship.

Information: Communication is reasonable open. Partners share information required to make the relationship work, including their objectives and goals, technical data and knowledge of conflicts, trouble spots or changing situations.

Integration: The partners develop linkages and share the ways of operation so that they can work together smoothly. They build broad connections between many people at many organizational levels. Partners become both teachers and learners.

Institutionalization: The relationship is given a formal status which clears responsibilities and decision processes. It extends beyond the particular people who formed it, and it cannot be broken on a whim.

Integrity: The partners behave toward each other in honorable ways that justify and enhance mutual trust. They do not abuse the information they gain, nor do they undermine each other.

2.2 Supply Chain Evaluation

Effective supply chain management envisioned as a solution to meet the constantly changing needs of the customer at low cost, high quality, short lead times and high variety. The motive behind the formation of supply chain arrangements is to increase channel competitiveness. Ahn and Lee (2004) propose an agent-based approach to improve the global efficiency of a supply chain by enabling participating companies to form a reasonably efficient supply chain dynamically and to minimize bullwhip effects in a supply chain via information sharing among cooperative agents. Talluri and Baker (2002) present a multi-phase mathematical programming approach for effective supply chain network design. Their methodology develops a combination of multiple criteria efficiency models, based on game theory and concepts, and linear integer programming methods. Schneeweiss (2003) identifies different classes of distributed decision-making problems in supply chain management. These problem classes are developed in various sciences like applied mathematics, operations research, economics and artificial intelligence, particularly indicating possible synergies. They point to those distributed decision-making problems that have been proven to be of major relevance for supply chain management. Frohlich and Westbrook (2002) divide such integration into supply and demand integration. Supply integration includes delivery, evaluating supplier based on quality and delivery performance, establishing long-term contract with supplier and the elimination of paperwork. Demand integration includes increased access to demand information throughout the supply chain to permit rapid and efficient delivery, coordinated planning and improved logistics communication. Treville et al. (2004) propose a framework for prioritizing lead time reduction in a demand chain improvement project, using a typology of demand chains to identify and recommend trajectories to achieve desirable levels of market mediation performance.

A question still remains outstanding is that what factors will result in successful supply chain relationships. It is also important to identify obstacles that that must be overcome to achieve success. The sidebar summarizes the findings of comprehensive research complete by Rosabeth Moss Kanter. Her study involves more than 500 interviews with managers from 37 firms in 11 different areas and countries that participate in collaborative arrangements. Table 2-2 and Table 2-3 summarize successful factors and common obstacles directly related to supply chain relationships. (Bowersox & Closs, 1996)

Table 2-2: Factors increasing likelihood of supply chain relationship success

Retailers	Manufactures
· High level cooperation	· Information sharing
· Similarity of goal/objectives	· Recognition of mutual benefits
· Clear communications	· Controlled implementation
· Senior management support	· Joint task force
· Control of inventory	· Commitment / resource dedication
	· Benefits realization

Table 2-3: Common obstacles confronted of supply chain relationships

Retailers	Manufactures
· Low-volume stock keeping units	· Lack of communication
· Resistance of manufactures to change	· Trust level
· Information systems	· Non-compatible systems
· Non-compatible data formats	· Understanding of technical issues
	· Resistance of customers to change
	· Readiness of retailers

2.3 Multiple Criteria Methods for Evaluation

2.3.1 Multiple Criteria Decision-Making

In MCDM, it is assumed that there exist a number of alternatives for the decision-maker to decide, where each alternative is described by its performance on a number of criteria, attributes or objectives. Stewart (1996) defines a criterion that is a particular point of view according to which alternatives may be assessed and rank-ordered. An attribute is a particular feature of the alternative with which a numerical measure can be associated. An objective is a specific direction of preference defined in terms of attribute. The aim of MCDM is to provide support to the decision-maker in the process of making the choice between alternatives and may include the generation of a purposed "optimal" solution and/or some form of preference ranking.

The MCDM problems have two distinct categories: (1) multi-attribute decision analysis is most common applicable to problems with a small number of alternatives in an environment of uncertainty and (2) multiple criteria optimization are most common applied to deterministic problems in which the number of feasible alternative is large. The single objective mathematical programming problems are studied extensively in the past forty years. However, single objective decision-making methods reflect an earlier and simpler era. Almost every important real world problem involves more than one objective, and decision-makers find it imperative to evaluate solution alternatives according to multiple criteria. One may need to extend the single criterion problems to the multiple criteria problems.

Multiple criteria optimization is most commonly applied to deterministic problems, difficult public service policies and less controversial issues in business and government, e.g. nuclear power plant sitting, location of an airport and road construction, etc. The article is most fully covered by Keeney and Raiffa (1976) and Steuer (1986). The success of DEA in the area of performance evaluation together with the formal analogies existing between DEA and MCDM have leaded some authors to use DEA as a tool for MCDM (Doyle & Green; 1993, Stewart, 1994). The equivalence between the notion of “efficiency” in DEA and that of “convex efficiency” in MCDM is discussed in Belton and Vickers (1993) and Stewart (1996).

2.3.2 Multiple Objectives Binary Integer Linear Programming

Liu et al. (2000) and Liu and Lai (2000) first propose the problem defined as follows. Suppose there are K feasible activities, numbered k =1, … , K; each activity consumes varying amounts of m resources to produce s products. Specifically, activity k consumes amounts a_{ik} of resource i, where i =1, … , m. Activity k produces c_{rk} of product r, where r =1, … , s. A possible combination of the K feasible activities is denoted by $w=(w_1, w_2, \dots, w_K)^T$, which is called decision combination unit (DCU) throughout this paper. If the k^{th} activity is performed, set w_k=1, otherwise set w_k=0. In total, there are 2^K of possible DCUs. The traditional linear optimization technique solves the problem by formulating it as a MOBILP as following:

Objective function

Maximize $y_r = c_{r1}w_1 + \dots + c_{rK}w_K, \quad r = 1, \dots, s.$ (2-1)

Minimize $x_i = a_{i1}w_1 + \dots + a_{iK}w_K, \quad i = 1, \dots, m.$

Subject to $w_k \in \boldsymbol{B}=\{0, 1\}, \quad k = 1, \dots, K.$

In the practical situation, these constants are generally taken to be positive, a_{ik} >0 and c_{rk} >0. The $m\times K$ matrix of *input* measures is denoted by $\boldsymbol{A}$ and the $s\times K$ matrix of *output* measures is denoted by $\boldsymbol{C}$. It can be expressed in matrix form:

Maximize $\boldsymbol{y}=\boldsymbol{Cw}$

Minimize $\boldsymbol{x}=\boldsymbol{Aw}$

Subject to $\boldsymbol{w}\in\boldsymbol{B}^K$.

Instead of considering optimization of the criteria, they use DEA to develop the envelopment surface on the set of DMUs, $\boldsymbol{\Omega}_D = \{(\boldsymbol{x}, \boldsymbol{y}) |\ \boldsymbol{x}=\boldsymbol{Aw}, \boldsymbol{y}=\boldsymbol{Cw}, \boldsymbol{w}\in\boldsymbol{\Omega}\}$ to characterize efficiencies and inefficiencies where $\boldsymbol{\Omega}$ is the set of all possible DCUs.

2.3.3 Data Envelopment Analysis

DEA is an analytical procedure developed for measuring the relative efficiency of DMUs that perform the same types of functions and have identical goals and objectives. Using DEA, the relative efficiency of DMUs that use multiple inputs to produce multiple outputs may be calculated. The weights used for each DMU are those which maximize the ratio between the weighted output and weighted input. DEA is a mathematical programming technique that calculates the relative efficiencies of n DMUs, based on multiple inputs and outputs. Given the data, we measured the efficiency of each DMU once and hence needed n optimizations, one for each *DMU* to be evaluated. Let the DMU_j to be evaluated on any trial be designated as DMU_o where o ranges from 1 to n. We solved the following fractional programming problem to obtain values for the input weight v_i and output weight μ_r as variables.

$$
\begin{aligned}
\text{Max} \quad & \theta = \frac{\mu_1 y_{1o} + \mu_2 y_{2o} + \ldots + \mu_s y_{so}}{v_1 x_{1o} + v_2 x_{2o} + \ldots + v_m x_{mo}} \\
\text{s.t.} \quad & \frac{\mu_1 y_{1j} + \mu_2 y_{2j} + \ldots + \mu_s y_{sj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots + v_m x_{mj}} \le 1, \quad j = 1, \ldots, n; \\
& v_i \ge 0, \quad i = 1, \ldots, m; \quad \mu_r \ge 0, \quad r = 1, \ldots, s.
\end{aligned} \qquad (2\text{-}2)
$$

where x_{ij} = the units of input i consumed by DMU_j, $i = 1, \ldots, m; j = 1, \ldots, n$.

y_{rj} = the units of output r produced by DMU_j, $r = 1, \ldots, s; j = 1, \ldots, n$.

v_i = the weight assigned to input i, $i = 1, \ldots, m$.

μ_r = the weight assigned to output r, $r = 1, \ldots, s$.

The constraints mean that the ratio of "virtual output" *v.s.* "virtual input" should not exceed 1 for every DMU. The objective is to obtain weights that maximized the ratio of DMU_o; the optimal objective value θ^* is at most 1. We convert this to managerial terms by assuming that all inputs and outputs have some nonzero worth; this is reflected in the weights v_i and μ_r being assigned some positive value. Weber (1996) applies DEA to evaluate suppliers for an individual product and demonstrate its advantages for such a system. It is found that significant reduction in costs, late deliveries and rejected materials can be achieved if inefficient suppliers became DEA efficient.

DEA is based on mathematical programming and uses for characterizing efficiencies and inefficiencies of DMUs with the same multiple inputs and outputs. The two DEA models are going to be briefly reviewed (Charnes et al. 1991; Ali, 1997; Cooper et al., 2000).

(1) CCR Model

Let us assume that we have n DMUs using m inputs to secure s outputs. Let us denote x_{ij} and y_{rj} the level of the i^{th} input and r^{th} output respectively observed at DMU_j. The technical input model (2-3) first is developed by Charnes, Cooper and Rhodes (1978). They develop a classical model, referred as the CCR model. A nonlinear programming model provides a new definition of efficiency for use in evaluating activities of not-for-profit entities participating in public programs. The CCR model generalizes the single-output and single-input classical engineering-science ratio definition to multiple inputs and outputs without requiring pre-assigned weights.

CCR Model — Input Orientation Primal Form (CCR_P-I)

$$
\begin{aligned}
&\text{Min } Z' = \psi - \varepsilon \sum_{r=1}^{s} s_r^{+} - \varepsilon \sum_{i=1}^{m} s_i^{-} \\
&\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^{+} = y_{ro}, \quad r = 1, \ldots, s; \\
&\quad \psi\, x_{io} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^{-} = 0, \quad i = 1, \ldots, m; \\
&\quad \lambda_j \geq 0,\ j = 1, \ldots, n; \quad s_r^{+} \geq 0,\ r = 1, \ldots, s; \quad s_i^{-} \geq 0,\ i = 1, \ldots, m; \\
&\quad \psi : \text{free in sign.}
\end{aligned}
\tag{2-3}
$$

CCR Model — Input Orientation Dual Form (CCR_D-I)

$$
\begin{aligned}
&\text{Max } T' = \sum_{r=1}^{s} \mu_r y_{ro} \\
&\text{s.t.} \quad \sum_{i=1}^{m} v_i x_{io} = 1; \\
&\quad \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, \ldots, n; \\
&\quad -v_i \leq -\varepsilon, \quad i = 1, \ldots, m; \\
&\quad -\mu_r \leq -\varepsilon, \quad r = 1, \ldots, s.
\end{aligned}
\tag{2-4}
$$

Several new constructs appear in this CCR model formulation. The variable "ε", a non-Archimedean (infinitesimal) constant, appears both in the primal objective function and as a lower bound for the multipliers in the dual problem. The scalar variable ψ^* is the proportional reduction applied to all inputs of DMU_o to improve efficiency. This reduction is applied simultaneously to all inputs and results in a radial movement toward the envelopment surface. The non-Archimedean ε in the primal objective function effectively allows the minimization over ψ^* to preempt the optimization involving the slacks. Thus, the optimization can be computed in a two-stage process with maximal reduction of inputs being achieved first, via the optimal ψ^*. Then, in the second stage, movement onto the efficient frontier is achieved via the slack variable. Evidently, the following two statements are equivalent:

(a) A DMU is efficient if and only if the following two conditions are satisfied.

(a´) the optimal $\psi^*=1$,

(b´) all slacks are zero.

(b) A DMU is efficient if and only if $T'^* = Z'^* = 1$.

In an output orientated CCR model, the focus is shifted from input resource minimization to the output production maximization without exceeding the given levels. From the output orientated CCR model, maximal output augmentation is again accomplished through the variable ϕ applied to the output vector of DMU_o.

CCR Model — Output Orientation Primal Form (CCR_P-O)

$$\begin{aligned}
\text{Max } & W' = \phi + \varepsilon \sum_{r=1}^{s} s_r^+ + \varepsilon \sum_{i=1}^{m} s_i^- \\
\text{s.t. } & \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io}, \quad i = 1, \ldots, m; \\
& \phi\, y_{ro} - \sum_{j=1}^{n} \lambda_j y_{rj} + s_r^+ = 0, \quad r = 1, \ldots, s; \\
& \lambda_j \geq 0,\ j = 1, \ldots, n; \quad s_r^+ \geq 0,\ r = 1, \ldots, s; \quad s_i^- \geq 0,\ i = 1, \ldots, m; \\
& \phi : \text{free in sign.}
\end{aligned} \tag{2-5}$$

If $\phi^*=1$ and all input and output slacks are equal to zero, then DMU_o is efficient and is operating on the frontier; otherwise, if $\phi^* \neq 1$ or (and) some input and (or) output slacks are nonzero, then DMU_o is inefficient and could improve its efficiency by either reducing its inputs or increasing its outputs over which management has control. A DMU is characterized as efficient in an input orientated CCR model if and only if it is characterized as efficient in the corresponding output orientated CCR model. The interpretation is similar to that applied in the input orientation model mentioned above. We note in Figure 2-1 and Figure 2-2 that while the envelopment surfaces are identical for both the input and output orientations for the CCR model. An inefficient DMU is projected to different points on the envelopment surface.

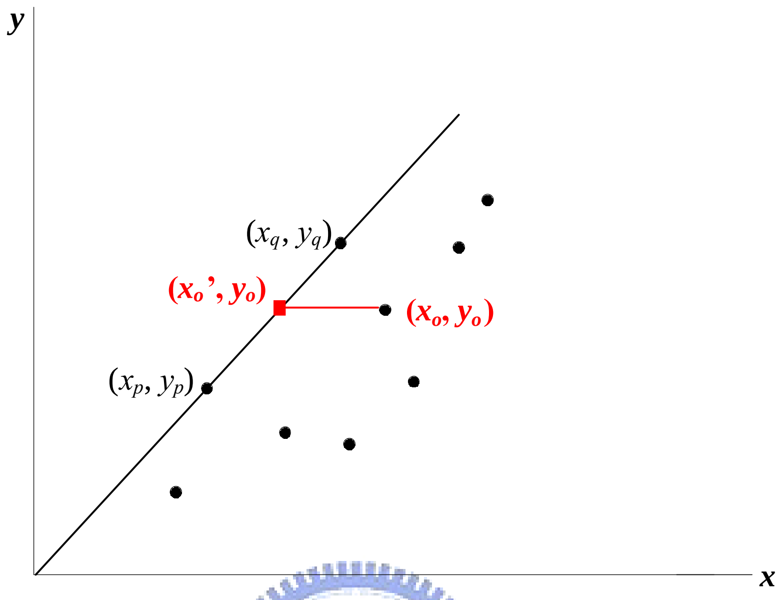

Figure 2-1: Envelopment surface for CCRP-I

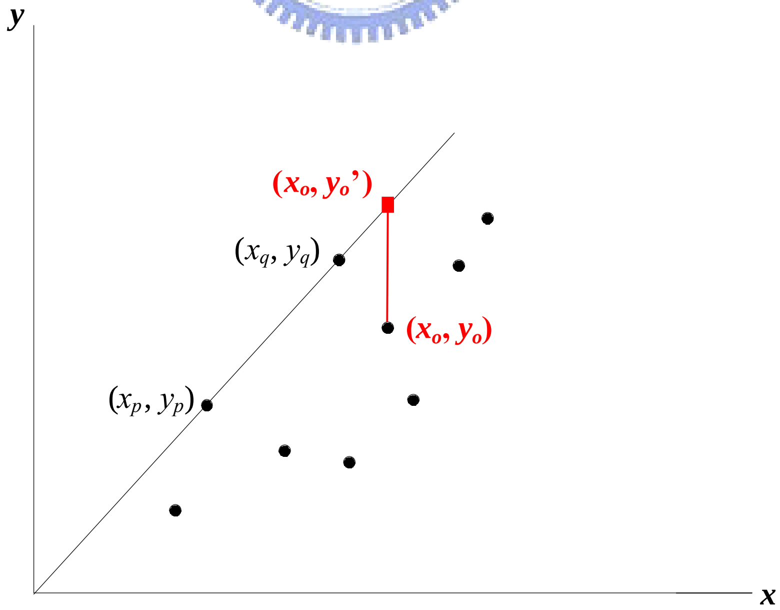

Figure 2-2: Envelopment surface for CCRP-O

(2) BCC Model

Banker, Charnes and Cooper (1984) develop BCC model which separate the inefficiency into technical and scale inefficiencies. A separate variable is introduced which makes it possible to determine whether operations are conducted in regions of increasing, constant and decreasing return-to-scale in multiple inputs and outputs situations.

BCC model also admits both input and output orientations, and the formulation is similar to that for CCR model. The particular point of selected projection is dependent on the employed DEA model and the orientation. For instance, in an input orientated BCC model, one focuses on maximal movement toward the frontier through proportional reduction of inputs, whereas in an output orientation, one focuses on maximal movement via proportional augmentation of outputs. The input orientated BCC model evaluates the efficiency of DMU_o by solving the following linear program and the model is presented below:

BCC Model — Input Orientation Primal Form (BCC_P-I)

$$
\begin{aligned}
\text{Min } & Z = \delta - \varepsilon \sum_{r=1}^{s} s_r^+ - \varepsilon \sum_{i=1}^{m} s_i^- \\
\text{s.t. } & \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro}, \quad r = 1, \ldots, s; \\
& \delta\, x_{io} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0, \quad i = 1, \ldots, m; \\
& \sum_{j=1}^{n} \lambda_j = 1; \\
& \lambda_j \ge 0,\ j = 1, \ldots, n; \quad s_r^+ \ge 0,\ r = 1, \ldots, s; \quad s_i^- \ge 0,\ i = 1, \ldots, m; \\
& \delta : \text{free in sign.}
\end{aligned}
\tag{2-6}
$$

BCC Model — Input Orientation Dual Form (BCC_D-I)

$$
\begin{aligned}
\text{Max } & T = \sum_{r=1}^{s} \mu_r y_{ro} - u_0 \\
\text{s.t. } & \sum_{i=1}^{m} v_i x_{io} = 1; \\
& \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \le 0, \quad j = 1, \ldots, n; \\
& -v_i \le -\varepsilon, \quad i = 1, \ldots, m; \\
& -\mu_r \le -\varepsilon, \quad r = 1, \ldots, s; \\
& u_0 : \text{free in sign.}
\end{aligned}
\tag{2-7}
$$

In the dual linear programs for input orientated BCC model, we should note that neither the convexity constraint $\sum_{j=1}^{n}\lambda_j = 1$ nor the variable u_0 appears in the formulation CCR model. The absence of the convexity constraint enlarges the feasible region for CCR from the convex hull considered in BCC model to the conical hull of (or the convex cone generated by) DMUs.

As can be seen from the formulation below, the essential difference between the previous input and output orientated BCC model is that the Linear Programming (LP) now maximizes on π to achieve proportional output augmentation. One focuses on maximal movement via proportional augmentation of outputs. If a DMU is characterized as efficient in CCR model, it will also be characterized as efficient with BCC model. In particular, a DMU is characterized as efficient with an output orientation if and only if it is characterized as efficient with an input orientation applied to the same data. BCC model with an output orientation is presented below.

BCC Model — Output Orientation Primal Form (BCC_P-O)

$$\begin{aligned}
\text{Max}\quad & W = \pi + \varepsilon\sum_{r=1}^{s} s_r^{+} + \varepsilon\sum_{i=1}^{m} s_i^{-} \\
\text{s.t.}\quad & \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^{-} = x_{io}, \quad i = 1, \ldots, m; \\
& \pi\, y_{ro} - \sum_{j=1}^{n}\lambda_j y_{rj} + s_r^{+} = 0, \quad r = 1, \ldots, s; \\
& \sum_{j=1}^{n}\lambda_j = 1; \\
& \lambda_j \ge 0,\ j = 1, \ldots, n; \quad s_r^{+} \ge 0,\ r = 1, \ldots, s; \quad s_i^{-} \ge 0,\ i = 1, \ldots, m; \\
& \pi : \text{free in sign.}
\end{aligned} \tag{2-8}$$

In an output orientation, the objective is to maximize output production while not exceeding the given resource levels. We again emphasize that this proportional output augmentation by itself may not be enough to achieve efficiency. Additional movement to the envelopment surface may be necessary and is accomplished via positive input and/or output slack values.

Finally, we should note in Figure 2-3 and Figure 2-4 that while the envelopment surfaces are identical for both the input and output orientations for BCC model. An inefficient DMU is projected to different points on the envelopment surface.

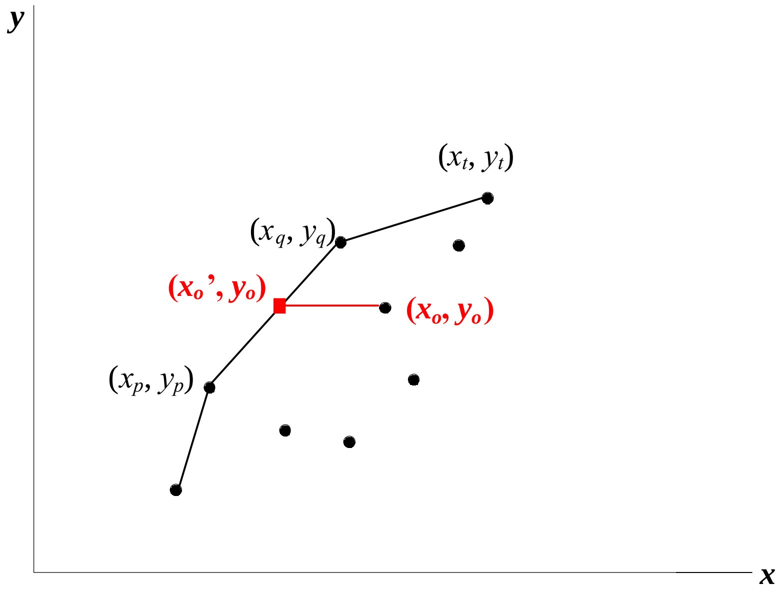

Figure 2-3: Envelopment surface for BCCP-I

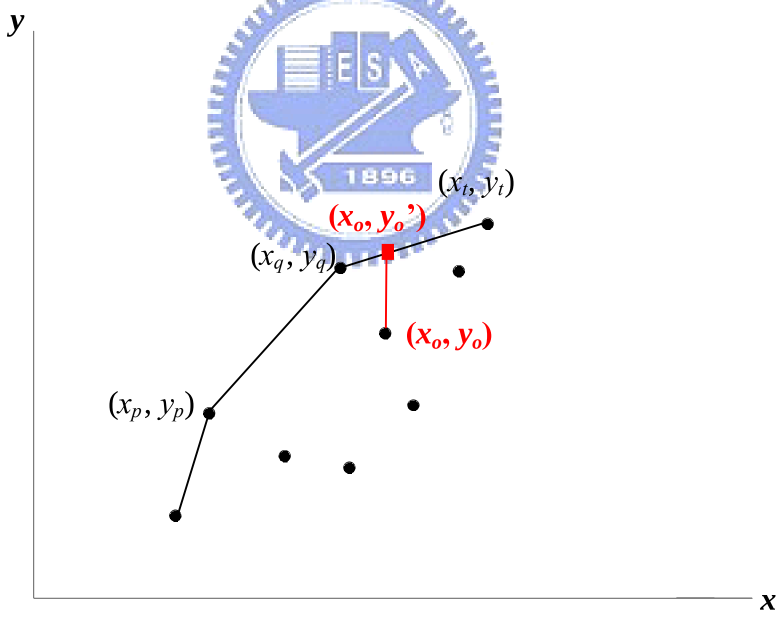

Figure 2-4: Envelopment surface for BCCP-O

(3) Specifications of DEA

Two DEA models, BCC model and CCR model, are employed in this study. The first one is variable return-to-scale (VRS) model and the second one is the DEA constant return-to-scale (CRS) model. The essential difference between the VRS model and the CRS model, input orientated model, is the addition of a new constraint $\sum_{j=1}^{n} \lambda_j = 1$. With this added constraint, the reference set is changed from the cone in the case of the CRS model to convex hull in the case of the VRS models. One result of this change is that the tested DMU is compared against a limited number of combinations. Banker and Thrall (1992) propose alternative method for determining return-to-scale in DEA. The methods for estimating return-to-scale in DEA are developed by Banker et al. (1984), Zhu and Shen (1995) and Banker et al. (1996).

CCR Return-To-Scale (RTS) Theorem (Banker and Thrall, 1992)

(a) If $\sum_{j=1}^{n} \lambda_j^* > 1$ in any alternate optima, then decreasing return-to-scale prevail.

(b) If $\sum_{j=1}^{n} \lambda_j^* = 1$ in any alternate optima, then constant return-to-scale prevail.

(c) If $\sum_{j=1}^{n} \lambda_j^* < 1$ in any alternate optima, then increasing return-to-scale prevail.

If we have a unique optimal solution in model (2-7), then CRS correspond to $u_0^* = 0$, DRS correspond to $u_0^* > 0$ and IRS correspond to $u_0^* < 0$ considered over all alternate optima and when we are on the efficient production frontier.

To avoid the misclassification, we use the recent result to determine the RTS classification. We employ the output orientated CCR and BCC models to define a scale efficiency measure by $\tau = \frac{\phi^*}{\pi^*} = 1$. If τ=1, DMU_o is called scale-efficient; otherwise, if τ>1 a DMU_o is called scale-inefficient. That is, let DMU_o solution and λ_j^* be an optimal solution associated with ϕ^*, then CRS prevail for DMU_o if and only of $\phi^* = \pi^*$, i.e., τ=1; otherwise, if $\phi^* \neq \pi^*$, i.e., τ>1 , then IRS prevail for DMU_o if and only of $\sum_{j=1}^{n} \lambda_j^* < 1$, and DRS prevail for DMU_o if and only of $\sum_{j=1}^{n} \lambda_j^* > 1$. Using this method, one does not have to worry about possible misclassification errors from multiple optimal solutions for λ_j^*, and the RTS classifications are readily obtained from the optimal solutions to the models (2-5) and (2-8).

The calculations of economies of scale have a direct interpretation in terms of the underlying dynamic evolution. A firm with decreasing return-to-scale has pushed its expansion too far, and management can be expected to consider the possibility of downsizing, laying off workers and reducing its scale of operations. Conversely, a firm with increasing return-to-scale will typically be engaged in rapid economic growth.

(4) Sensitivity analysis of DEA

Charnes et al. (1985) investigate the sensitivity of CCR model and Charnes and Neralic (1990) explore the sensitivity of the additive model in DEA. Zhu (1996) and Seiford and Zhu (1998) suggest a new approach to sensitivity analysis by using upward proportional variations of inputs and downward proportional variations of outputs on a modified CCR model. This results in sufficient conditions for the changes but does not alter the efficiency of DMUs. An efficient DMU is said to be robust to a given increase of an input, or a given decrease of an output, if the DMU remains efficient after the change.

$$\begin{cases} x'_{io} = \rho\, x_{io}, & \rho \geq 1, \quad i = 1, \ldots, m. \\ y'_{ro} = \varpi\, y_{ro}, & 0 < \varpi \leq 1, \quad r = 1, \ldots, s. \end{cases} \tag{2-9}$$

In model (2-9), x_{io} and y_{ro} are the inputs and outputs of DMU_o. ρ and ϖ are the scalar numbers of input and output variables. It is assumed that inputs and outputs of remaining DMUs are unchanged.

3. THE VAHP METHOD FOR SELECTING SUPPLIERS

3.1 Introduction

Supplier selection has received extensive attention in supply chain management. Yahya and Kingsman (1999) integrate collaborative purchasing program where one of the aims is to select suppliers. They illustrate a new approach based on the use of Saaty's AHP that is developed to assist in multiple criteria decision-making problems. In this section, we compare the appropriate total ranking sum of the selection number of rank vote to figure out the total weights of suppliers for selection, after determining the weights in a selected rank. This investigation presents a novel weighting procedure in replace of AHP's paired comparison for selecting supplier. We provide a more simple method than AHP that is called Voting Analytic Hierarchy Process (VAHP), but not to lose the systematic approach of deriving the weights to be used and for scoring the performance of suppliers.

The AHP has found widespread application in decision-making problems, which involve multiple criteria in systems of many levels. The strongest features of the AHP are that they generate numerical priorities from the subjective knowledge expressed in the estimates of paired comparison matrices. The method is surely useful in evaluating suppliers' weights in marketing or in ranking order, for instance. It is, however, difficult to determine suitable weight of each alternative in order. Noguchi et al. (2002) propose a new ordering to solve the weights of ranks by considering feasible solutions of the constraint set in linear program.

3.2 Related Theories and Models

3.2.1 Analytic Hierarchy Process

The multiple criteria aspects of decision analysis arise because outcomes must be evaluated in terms of several objectives. This is stated in terms of properties, either desirable or undesirable, that determine the decision-maker's preference for the outcomes. The purpose of the value model is to take the various outcomes of the system models, determine the degree to which they satisfy each of the objectives, and then make the necessary trade-offs to achieve at a ranking for the alternatives that correctly expresses the preferences of the decision-maker. The AHP developed by Saaty (1980) is originally applied to uncertain decision problems with multiple criteria, and has been widely used in solving problems of ranking, selection, optimization and prediction decisions. Generally, the AHP separates the complex decision problems into elements within a simplified hierarchical system. Through the pair-wise comparison of these principal eigenvector is then computed for the priority vector, which provides consistency measure of a decision-maker. The AHP methodology consists of the following four main steps:

(1) Develop the hierarchical structure (missions, criteria and alternatives).

(2) Assign relative importance to each selection criterion of the mission.

(3) Rank the alternatives under each criterion.

(4) Rank each alternative's contributions to the mission.

The value model for selecting the objectives is developed using a hierarchy of objectives and sub-objectives, as shown in Figure 3-1. To quantify the model, a unit of measurement must be assigned to the lowest members of the hierarchy. When the analysis turns to such intangible considerations as management, risk and quality, finding a single variable whose direct measurement will provide a valid indicator is rare. In fact, each of these measures is a composite of a multitude of elements, weighted and summed together in what many would view as an arbitrary manner.

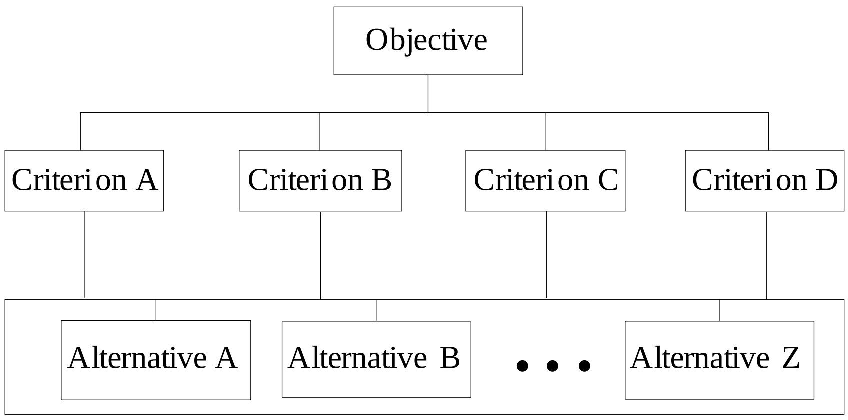

Figure 3-1: Summary of three-level hierarchy for alternatives

The seven pillars of the AHP are: (Saaty and Vargas, 2001)

(1) **Ratio scale, proportionality and normalized ratio scales** are central to the generation and synthesis of priorities, whether in the AHP or in any multiple criteria method

that needs to integrate existing ratio scale measurements with its own derived scales; in additional, ratio scales are the only way to generalize a decision theory to the case of dependence and feedback because ratio scales can be both multiplied and added – when they belong to the same scales such as a priority scale.

(2) **Reciprocal paired comparison** is used to express judgments semantically automatically linking them to a numerical fundamental scale of absolute numbers from which the principal eigenvector of priorities is then derived; the eigenvector shows the dominance of each element with respect to the other elements. The AHP has at least three modes to achieve the ranking of the alternatives: a) *Relative,* which ranks a few alternatives by comparing them in pairs and is particularly useful in new and exploratory decisions. b) *Absolute*, which rates an unlimited number of alternatives once at a time on intensity scales constructed separately for each coving criterion and is particularly useful in decisions where there is considerable knowledge to judge the relative importance of the intensities and develop priorities for them. c) *Benchmarking*, which ranks alternatives by including a known alternative in the group and comparing the other against it.

(3) **Sensitivity of the principal right eigenvector** to perturbation in judgments limits the number of elements in each set of comparisons to be few and requires that they be homogeneous.

(4) **Homogeneous and clustering** are used to extend the fundamental gradually from cluster to adjacent cluster, eventually enlarging the scale from 1-9 to 1-∞.

(5) **Synthesis that can be extended to dependence and feedback** is applied to the derived ratio scales to create a uni-dimensional ratio scale for representing the overall outcome. Synthesis of the scales derived in the decision structure can only be made to yield correct outcomes on known scales by additive weighting. It should be carefully noted that additive weighting in a hierarchical structure leads to a multi-linear form and hence is nonlinear.

(6) **Rank preservation and reversal** can be shown to occur without adding or deleting criteria, such as by simply introducing enough copies of an alternative or for other reasons; it follows that any decision theory must have at least two modes of synthesis.

(7) **Group judgment** must be integrated once at a time carefully and mathematically, taking into consideration when desired the experience, knowledge and power of each person involved in the decision, without the need to force consensus, or to use majority or other

ordinal ways of voting. The theorem regarding the impossibility of constructing a social utility function from individual utilities that satisfies four reasonable conditions, which found their validity with ordinal preferences, is no longer true when the preferences of cardinal ratio scale are used as in the AHP.

The strength of AHP lies in its ability to structure a complex, multi-person, multi-attribute problem hierarchically, and then to separately investigate each level of the hierarchy, combining results as the analysis progresses. Pair-wise comparison of the factors is undertaken, using a scale indicating the strength for which one higher-level factor dominates a lower-level factor. This scaling process can then be translated into priority weights or scores for ranking the alternatives. An integrated AHP and preemptive goal programming based multiple criteria decision-making methodology is developed to take into account both qualitative and quantitative factors in supplier selection (Partovi et al., 1990; Wang et al., 2004). AHP has been successfully applied in many situations and is designed for multiple criteria decisions, such as allocating order quantities for inventory (Partovi & Hopton, 1994), gauging organization performance (Lee et al., 1995; Rangon, 1996), weapon systems (Cheng, 1996), antivirus software (Mamaghani, 2002), total quality management (Dalu & Deshmukh, 2002), mutual funds (Saraoglu & Detzler, 2002) and project risk management (Dey, 2002).

3.2.2 Vote-Ranking Method

As for ranking of alternatives, one of the most familiar methods is to compare the weighted sum of their votes after the suitable weights of each alternatives has been determined. Cook and Kress (1990) present a procedure by applying data envelopment analysis to the problem of rank ordering the candidates in a preferential election. In such an election, each voter selects a subset of the candidates and places them in rank order; the poll organizer then establishes for each candidate a standing of the number of first, second, third place votes etc. received. And then, Green et al. (1996) develop it by setting specific constraints to weights. In what follow, this procedure is known as the "Green's method", which consists of the following two methods to set constraints: (1) the difference of weights between e^{th} place and $(e+1)^{\text{th}}$ place for any e is allowed to be zero; (2) the above difference of weight must be strictly larger then zero.

Let us assume that there are more than one, say L (number) criteria for ranking. Next, let g be the number of voters, and E be the number of places. u_{le} denotes the weight of the e^{th} place with respect to the l^{th} criterion. Every candidate wishes to assign each weight u_{le} in order to maximize the weighted sum of votes to the l^{th} criterion that is the score θ_{ll} becomes the largest. The "Green's weak ordering" is defined as follows:

$$\begin{aligned} \theta_{ll} &= \text{Max} \sum_{e=1}^{E} u_{le} x_{le} \\ \text{s.t.} \quad & \sum_{e=1}^{E} u_{le} x_{pe} \le 1, \qquad p = 1, \ldots, L; \\ & u_{l,\,e-1} - u_{le} \ge d(e-1, \varepsilon) = \varepsilon \ge 0, \qquad e = 2, \ldots, E; \\ & u_{l1} \ge u_{l2} \ge \ \ldots \ \ge u_{lE} \ge 0. \end{aligned} \tag{3-1}$$

The "Green's strong ordering" is defined as follows:

$$\begin{aligned} \theta_{ll} &= \text{Max} \sum_{e=1}^{E} u_{le} x_{le} \\ \text{s.t.} \quad & \sum_{e=1}^{E} u_{le} x_{pe} \le 1, \qquad p = 1, \ldots, L; \\ & u_{le} - u_{l,\,e+1} \ge d(e, \varepsilon) = \varepsilon > 0, \qquad e = 1, \ldots, E-1; \\ & u_{l1} \ge u_{l2} \ge \ \ldots \ \ge u_{lE} \ge 0. \end{aligned} \tag{3-2}$$

Here, x_{le} are the total votes of the l^{th} criterion for the e^{th} place by g voters. We will obtain some number x_{l1} of votes as first place, x_{l2} as second place, … , x_{le} as e^{th} place, l =1, … , L, and e =1, … , E. $d(e, \varepsilon)=\varepsilon$ appearing in model (3-2) constraint stands for the difference in weights between e^{th} place and $(e+1)^{th}$ place.

The above-mentioned Green's method, however, has the following shortcoming: (a) application to concrete examples and (b) the change of ε influence the total ranking of objects. Especially, they do not examine (b) at all. The influence of ε can be analyzed by considering the feasible region of solutions (weights) obtained by LP, which is affected by the number of votes to the objects.

Noguchi et al. (2002) examine the application of Green's method and showed different weights among objects to different results of ranking. Moreover, we do not only apply Noguchi's strong ordering to a single–purpose problem, but also multi-purposes problem such as the supplier selection problem in a business corporation. In the total ranking method, one wants to set weights a particular constraint, "strong ordering" can be employed, which is characterized by the following constraint:

(a´) $u_{le} \ge \varepsilon = \dfrac{1}{g(1+2+\ldots+E)} = \dfrac{2}{gE(E+1)}$, and (b′) $u_{l1} \geq 2u_{l2} \geq 3u_{l3} \geq \ldots \geq E\,u_{lE}$.

Now we explain about the inequalities (a′). First of all, u_{le} should be positive in order not to lose information about the last place. We add the constraint $u_{le} \geq \varepsilon > 0$. The difference in weights between $(e-1)^{\text{th}}$ and e^{th} place should be changed step by step to the last place. These weights should satisfy following inequalities:

$$(u_{l1} - u_{l2}) > \ldots > (u_{l,e-1} - u_{le}) > \ldots > (u_{l,E-1} - u_{lE}) > 0\,.$$

Then, since $u_{le} - u_{l,e+1} < u_{le} - \frac{e-2}{e-1}u_{l,e+1}$, in order to make the weight of "strong ordering", replace > by ≥, i.e., we set

$$u_{l,e-1} - u_{le} \geq u_{le} - \frac{e-2}{e-1}u_{l,\,e+1}$$

$$\Rightarrow \qquad u_{l,\,e-1} \geq 2u_{le} - \frac{e-2}{e-1}u_{le} \qquad (\text{since } u_{le} \geq u_{l,\,e+1})$$

$$\Rightarrow \qquad u_{l,\,e-1} \geq \frac{e}{e-1}u_{le}$$

$$\Rightarrow (e-1)u_{l,\,e-1} \geq e u_{le}$$

The value of ε is adjusted by both the number of votes and place. Consequently, we derive inequalities (a′) from the value of ε and inequalities (b′). In this multiple criteria case, the "Noguchi's strong vote-ranking" is defined as follows:

$$\begin{aligned} \theta_{ll} &= \text{Max} \sum_{e=1}^{E} u_{le}x_{le} \\ \text{s.t.} \quad & \sum_{e=1}^{E} u_{le}x_{pe} \leq 1, \qquad p = 1, \ldots, L; \\ & e\,u_{le} \geq (e+1)u_{l,\,e+1}, \qquad e = 1, \ldots, E-1; \\ & u_{lE} \geq \varepsilon = \frac{2}{gE(E+1)}. \end{aligned} \qquad (3\text{-}3)$$

3.3 A Example for Umbrella Scheme of Malaysia's Furniture Industry

Liu and Hai (2005a, 2005c) propose six steps procedure for assessing and selecting suppliers with numerical example for the Umbrella Scheme of Malaysia's furniture industry that is from the paper of Yahya and Kingsman (1999). The problem is to select one of ten suppliers. The first step is structuring the problem into a hierarchy (see Figure 3-2). We set the objective for selecting suppliers on the top level. On the first level is that eight criteria contribute to the objective. On the second level is that eight criteria are decomposed into thirteen sub-criteria. On the third level is that the weights are transferred by criteria and sub-criteria. Finally, the ten suppliers will be assessed by these weights.

Figure 3-2: Hierarchy of supplier selection

3.3.1 Step 1: Select Supplier Criteria

We take sixty respondents participated as an example in this study, who were all managers and supervisors of company. The criteria obtained from group decision fall into two categories, objective and subjective criteria. The objective criteria are those that can be evaluated using factual data, which include quality, delivery, responsiveness, technical capability, facility and financial in Table 3-1.

Table 3-1: The measurement guidelines for the factors in the supplier rating

Factors and definitions	Types of measurement	Scales of measurement
Quality: Customer Reject Two sources of customer rejects are: Goods returned within 8 months warranty Collection delayed due to quality problem	Quantity of defect Type of defect Seriousness of defect	None, Low, Acceptable, High None, Minimum, Acceptable, High None, Insignificant, Minor, Major
Quality: Factory Audit Scored based on monthly factory audit performed by officers. Measurement by violations in standard specification of raw material, assembly and finishing activities.	Number of violations Seriousness of violation	Low, Acceptable, High Insignificant, Minor, Major
Responsiveness: Urgent Delivery Delivery within a two weeks lead-time. Measurement by delays beyond two weeks.	Frequency of delays Duration of delays	None, Low, Sometimes, High Number of weeks
Responsiveness: Quality Problems Defined by response time, time taken by the supplier to take action on the complaint and turn around time, time taken to solve problem.	Response time Turn around time	Number of days Number of weeks
Discipline: Honesty Determine by supplier honesty on transaction, commitment and negotiation related on the scheme and customer. Subjective assessment by managers.	Frequency of untruths Seriousness	Never, Low, High Insignificant, Minor, Serious
Discipline: Procedural compliance Supplier attitude toward compliance to rules, guidelines and polices of the scheme.	Frequency of violations Impact of violations	Never, Low, Normal, High Minimal, Normal, Serious
Delivery Number of cancelled and delayed orders where supplier unable to fulfill the delivery commitment	Cancelled orders Delayed orders	None, Low, High Low, Acceptable, High
Management: Attitude Supplier attitude towards: Improvement (willingness, etc.) Cooperation Business(positive thinking, hardworking)	Grading on all three separately	Strong, Adequate, weak
Management: Business Skill Suppliers' skills in terms of customer service, managing employees, managing process	Grading on all three	Effective, Adequate, weak
Technical Capability: Technical Problem Solving Supplier ability to proved corrective and preventive action on technical problem	Ability to find Solution Completeness of solution	High, Normal, Low Full, Temporary fix, Unable
Facility: Machinery Amount of machinery, rang and level of a automation and machine maintenance	Amount of machinery Range of machinery Maintenance	Ample, Adequate, Inadequate Wide, Normal, Narrow Well, Adequate, Inadequate
Facility: Layout Building structure, material storage, production process and space availability	Building Structure Material Storage Production Process	Closed, Partially closed, mainly open Accurate/clean/safe, Normal, Messy/unsafe Smooth/clean/spacious, Normal, Jam/messy
Facility: Infrastructure (for furniture) Critical infrastructure(communication, modes, location accessibility, etc) basic infrastructure(labor availability, environmental control, transportation)	Critical Infrastructure Basic Infrastructure	Strong, Adequate, weak Strong, Adequate, weak

* Source: Yahya and Kingsman (1999).

3.3.2 Step 2: Structure the Hierarchy of the Criteria

We use the AHP to identify sub-criteria under each criterion and to investigate each level of the hierarchy separately. The thirteen sub-criteria are factory audit, customer reject, urgent delivery, quality problems, honesty, procedural compliance, attitude, business skill, product range, technical problem solving, machinery, infrastructure and layout.

3.3.3 Step 3: Prioritize the Criteria and Sub-criteria

(1) The first stage

Let us suppose that there are sixty managers (or voters) in the study and they select different order for the candidates of criteria or sub-criteria. Let us assume eight criteria: quality, responsiveness, discipline, delivery, financial, management, technical capability and facility. The criteria are regarded as candidates. We get eight order from one to eight and sum up every vote in Table 3-2. It commonly happens that, when one has to select among many objects, a particular object is rated as the best in one evaluation, while others are selected by other evaluation methods. The managers get the order of criteria but not to get weights. The weight of each ranking is determined automatically by the total votes.

Table 3-2: Priority votes of eight criteria from sixty respondents

Criteria	1st	2nd	3rd	4th	5th	6th	7th	8th	Total
Quality	15	5	5	9	12	4	0	10	60
Responsiveness	12	11	15	6	4	1	4	7	60
Discipline	7	10	8	10	9	6	3	7	60
Delivery	20	16	10	11	3	0	0	0	60
Financial	1	6	1	9	12	9	11	11	60
Management	1	5	7	7	5	13	15	7	60
Technical Capability	2	5	2	3	7	16	20	5	60
Facility	2	2	12	5	8	11	7	13	60
Total	60	60	60	60	60	60	60	60	

(2) The second stage

We use the same method to find the priority votes of thirteen sub-criteria in Table3-3.

Table 3-3: Priority votes and weights of thirteen sub-criteria

Criteria	Votes 1st	Votes 2nd	Weights	Criteria	Votes 1st	Votes 2nd	Weights
Quality				Management			
Factory Audit	25	17	0.783 (*0.439*)	Attitude	53	2	1.000 (0.572)
Customer Reject	31	28	1.000 (*0.561*)	Business Skill	6	45	0.747 (0.428)
Responsiveness				Technical Capability			
Urgent Delivery	42	16	1.000 (*0.611*)	Product Range	55	5	1.000 (0.558)
Quality Problems	6	37	0.637 (*0.389*)	Technical Problem Solving	5	55	0.792 (0.442)
Discipline				Facility			
Honesty	44	16	1.000 (*0.531*)	Machinery	40	11	1.000 (*0.409*)
Procedural Compliance	16	44	0.883 (*0.469*)	Infrastructure	20	20	0.779 (*0.319*)
				Layout	0	19	0.666 (0.272)

*(   ): the total weights of the criteria equal to one by normalization.

3.3.4 Step 4: Calculate the Weights of Criteria and Sub-criteria

We use Noguchi's vote-ranking method to calculate the weights of criteria and sub-criteria.

(1) The first stage

We use the votes of Table 3-2 and find these weights of eight criteria from model (3-3). Figure 3-2 shows that weights for quality, responsiveness, discipline, delivery, financial, management, technical capability and facility are 0.896, 0.924, 0.877, 1.000, 0.790, 0.796, 0.780 and 0.803, respectively. After normalize these data, the results are 0.130, 0.135, 0.128, 0.146, 0.115, 0.116, 0.113 and 0.117.

(2) The second stage

We take the votes of Table 3-3 with the same method to get the weights of the sub-criteria in Figure 3-2. The second level gives the normalized values for all the thirteen sub-criteria. The sum of weights for sub-criteria must be added up to one in specific criterion. So the quality criterion performance will be made up from weighting "Factory Audit" performance by 0.439 and "Customer Reject" by 0.561. Finally, we will use the same methodology to find these weights of these sub-criteria in columns 4 and 8 of Table 3-3.

(3) The third stage

The values in the bottom level are the global weights for each of the thirteen sub-criteria. In Figure 3-2, the number 0.057 is equal to the "Quality" criterion score 0.130 product the "Factory Audit" sub-criterion score 0.439. The actual performance data is collected for these weights in the bottom level. They will be used directly to calculate the overall rating of the suppliers.

3.3.5 Step 5: Measure Supplier Performance

A major problem was thus to ensure consistency between the managers and avoid any bias creeping in. A set of standard guidelines was set up after discussions with the managers (or voters) of the company. It is agreed that all performance scores would be based on an ten points grade scale. Each grade would have an adjective descriptor and an associated point score or range of point scores. The managers preferred in the first instance to make their judge on the qualitative scale of adjectival descriptors. The general performance score guidelines are given in Table 3-4. Therefore each supplier can be awarded a "score" from one to ten on sub-criteria.

3.3.6 Step 6: Identify Supplier Priority

Simple score sheets were provided to assist the manager to record the scores for each supplier on each of the weights of Level 3. Once the weighted scores for each criterion have been determined, then it is relatively easy to calculate the resulting supplier rating scores. An example of this supplier is shown in Table 3-5. The supplier rating value for supplier-1 is obtained by summing up the products of the respective elements in columns 3 and 4 for each row, given in the final column, over all the rows to give a value of "8.057". The rating method used in supplier-1, can also be used to find the total weighted scores of the other nine suppliers. The supplier with the highest supplier rating value should be regarded as the best performing supplier and the rest can be ranked.

Table 3-4: Supplier criteria score guideline

Scores	Grades	Descriptions
10	Exceptional	Demonstrates substantially excellence performance, has been in the excellence for last 12 months.
9/8	Excellent	Exceeds officers and customer expectation, demonstrates extra effort and is superior to vast majority of suppliers.
7/6	Good	Meet officers and customer expectation.
5	Acceptable	Meet minimum officers' requirement.
4/3	Needs Attention	Overall performance does not meet officers and customer minimum acceptance level.
2	Poor	Overall performance is well below officers and customer acceptance level and is inferior to vast majority of suppliers.
1	Bad	Performance has not been improved, and has been in poor band for last 12 months.

Table 3-5: Rating of supplier-1

Criteria	Sub-Criteria	Weights	Scores	Weighted Scores
Quality	Factory audit	0.057	8	0.456
	Customer reject	0.073	7	0.511
Responsiveness	Urgent Delivery	0.082	9	0.738
	Quality Problems	0.053	9	0.477
Discipline	Honesty	0.068	7	0.476
	Procedural Compliance	0.060	6	0.360
Delivery	Delivery	0.146	7	1.022
Financial	Financial	0.115	9	1.035
Management	Attitude	0.066	7	0.462
	Business Skill	0.050	9	0.450
Technical Capability	Technical Problem Solving	0.063	9	0.567
	Product Range	0.050	9	0.450
Facility	Machinery	0.048	9	0.432
	Infrastructure	0.037	9	0.333
	Layout	0.032	9	0.288
Total Weight Scores				**8.057**

3.4 The Selection of Shipbuilding Corporations

3.4.1 The Selection Process

Taiwan government is urged to establish its independent shipbuilding capability. In order to develop shipbuilding industry and in line with enhancing the development of national defense-related industries, the Ministry of National Defense (MND) of Taiwan may commission private sectors to build warship. Government agencies follow national defense policies to consolidate efforts of the private sectors to develop national defense technology industries. Domestic production shall be given priority.

MND is changing their decision processes. MND is increasingly departing from authoritarian styles of management and developing systems to encourage private sectors to participate. This section describes the process for the MND of Taiwan to select shipbuilding corporations. That would involve multiple officers to participate the selection process.

A "top-down" way of thinking could be used to guide the formulation of decision hierarchy. From this perspective, participants would gain a broader understanding of the decision problem and design a better and more integrated decision hierarchy to contribute to better decisions. Therefore, MND needs to form a group of decision-makers (DM1) that may include six officers of system analyst, two effectiveness assessment directors, two shipbuilding manager and five professors for assessment of weapon system. Another group of decision-makers (DM2) consists of twelve officers of shipbuilding engineers and manager of Naval Shipbuilding and Development Center (NSDC). A task force (TF) unit is formed to execute the administrative work of the shipbuilding selection.

Firstly, in the group decision setting, DM1 and DM2 are provided with relevant information and reports provided by TF. All DM1 and DM2 were briefed on the concept and definition of "hierarchy of criteria and sub-criteria" collected for historical data of shipbuilding corporations. Then DM1 and DM2 were asked to check, review and discuss them. The criteria, sub-criteria and alternatives should be expressed in fairly general terms and should be well understood by all DMs.

The second task is to assist individual DM1 in assessing the relative importance of the various criteria and sub-criteria and the relative ranks among available candidates on different criteria and sub-criteria. DM2 use the data of "sub-criteria" provided from DM1 and rank these shipbuilding corporations in sub-criteria. Finally, TF show that different weights among objects give rise to different results of ranking.

3.4.2 The Six Steps of Shipbuilding Corporations Selection

Liu and Hai (2006b) propose six-step procedure for selecting three shipbuilding corporations for Taiwanese Navy. These shipbuilding corporations will be illustrated:

CFSC has built for international as well as domestic customers that include Norwegian and Japanese owners, as well as the Taiwanese Navy and Coast Guard. The new shipbuilding in the past include oil and chemical tankers up to general product carriers, high-tech marine research vessels and high speed patrol boats.

CSC is a state-owned enterprise with its head office in Kaohsiung of Taiwan and two shipyards located separately in Keelung and Kaohsiung. The services are extended over commercial and naval shipbuilding, ship repairing, manufacturing and diversified operations.

JSSC is specialized in shipbuilding ocean-going vessels, with continuing elevating technical ability and improving the quality of human resources. Its product lines include fishing vessels, Taiwan Coast Guard Patrol vessel and cargo conversion.

(1) Step 1: Identify the Shipbuilding Corporations' Criteria

DM1 use a board or group decision method to determine the criteria and sub-criteria for selecting shipbuilding corporations. These criteria and sub-criteria are individually presented to each participant that is received in Table 3-6.

Table 3-6: Summary of the performance metrics

Organization Metrics	Performance Metrics
Culture	**Quality**
Feeling of trust (FOT)	On time to the finish (OTF)
Management attitude/outlook (MAO)	Conformance quality (CQ)
Vision/strategic fit (VST)	Quality philosophy (QP)
Management	**Price**
Finance/marketing/performance (FMP)	Initial price (IP)
Communication openness (CO)	Conformity to cost structure (CCS)
Relationship/relationship closeness (RRC)	**Material**
Share of information (SOI)	Supply chain management (SCM)
Technology	Inventory/material strategy (IMS)
Include manufacture facilities/ personnel and response capability	Logistic support capability (LSC)
	Flexibility
	Service/delivery capability (SDC)
	Conflict resolution (CR)
	Design changes (DC)

(2) Step 2: Structure the Problem Hierarchy

DM1 use a hierarchical structure to construct a complex, multi-person, multi-attribute problem, in order to separately investigate each level of the hierarchy. The reason for this step is to decompose the selected suppliers and to make criteria on a given level with respect to the related elements in the model, as shown in Figure 3-3.

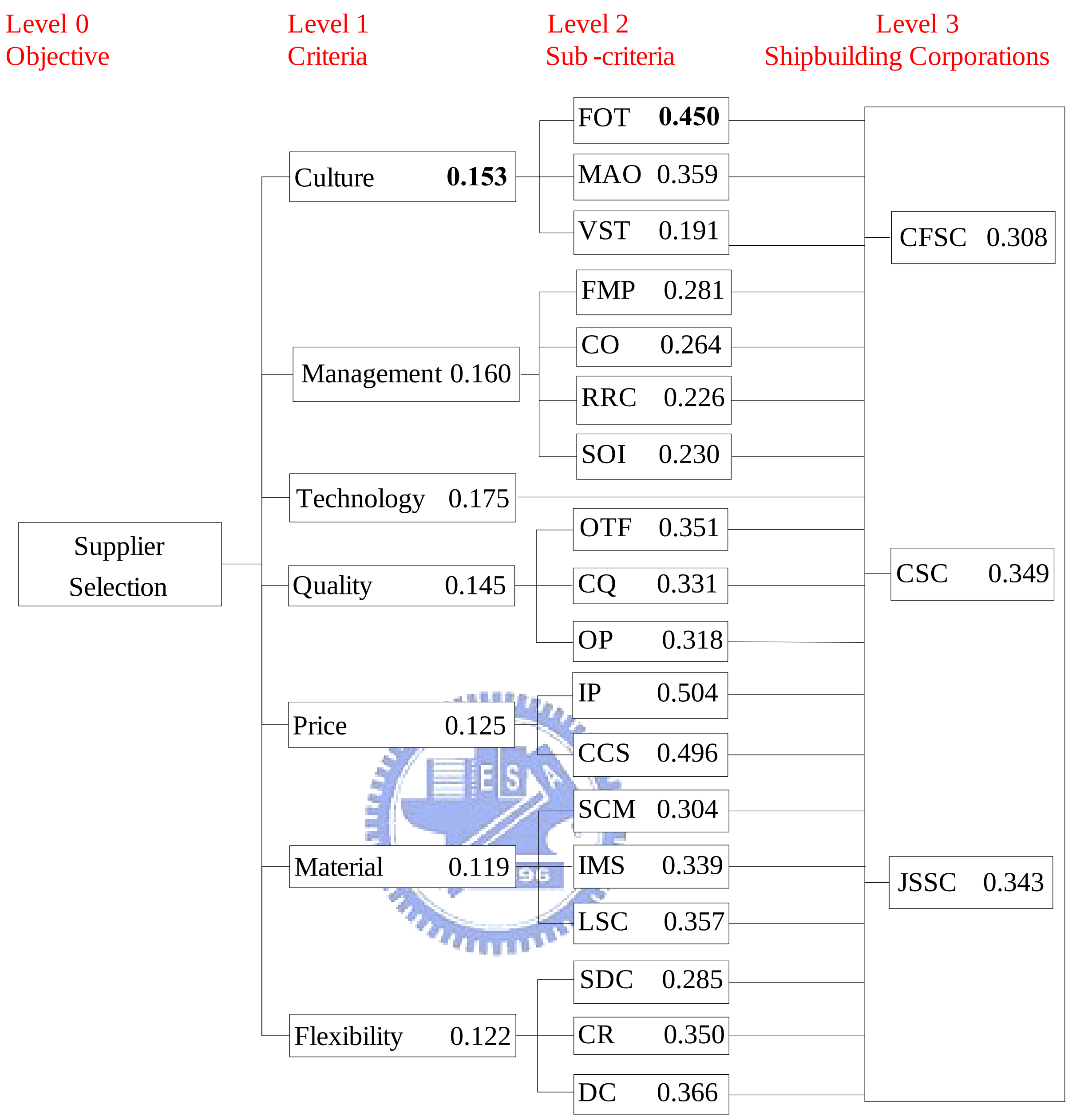

Figure 3-3: Hierarchy for selecting shipbuilding corporations

(3) Step 3: Establish the Votes of Priority

(a) Priority votes of criteria and sub-criteria

Weights are assigned to each alternative on the basis of its relative contribution to each criterion. For this purpose, DM1 propose seven criteria: organization metrics (culture, management and technology) and performance metrics (quality, price, material and flexibility). DM1 show the order of the seven criteria and the votes of each are shown in Table 3-7. Then, DM1 list the priority votes of sub-criteria in fixed first criterion in Table 3-8.

Table 3-7: Priority votes of seven criteria

Criteria	1st	2nd	3rd	4th	5th	6th	7th	Total
Culture	1	7	2	0	0	4	1	15
Management	5	0	10	0	0	0	0	15
Technology	11	2	0	1	1	0	0	15
Quality	1	5	3	0	6	0	0	15
Price	0	1	0	7	1	1	5	15
Material	0	1	0	0	6	1	7	15
Flexibility	0	0	1	5	0	8	1	15
Total	18	16	16	13	14	14	14	105

Table 3-8: Priority votes and weights of eighteen sub-criteria

Criteria	Votes			Weights	Criteria	Votes			Weights
	1st	2nd	3rd			1st	2nd	3rd	
Culture					Price				
FOT	13	4	1	0.450	IP	8	7		0.504
MAO	5	11	0	0.359	CCS	7	8		0.496
VST	0	1	10	0.191					
Management					Material				
FMP	10	1	1	0.281	SCM	2	3	10	0.304
CO	3	10	1	0.264	IMS	5	7	3	0.339
RRC	0	2	11	0.226	LSC	8	5	2	0.357
SOI	2	2	2	0.230					
Quality					Flexibility				
OTF	7	6	2	0.351	SDC	0	2	13	0.304
CQ	5	4	6	0.331	CR	6	8	1	0.339
OP	3	5	7	0.318	DC	9	5	1	0.357

(b) Priority votes of shipbuilding corporations

DM2 follow the criteria and sub-criteria that are defined by DM1. The same procedure is carried out for the remaining three shipbuilding corporations, with different sub-criteria being set. DM2 show the votes from first to third in Table 3-9.

Table 3-9: Priority votes and weights of three shipbuilding corporations

Corp.	Votes			Weights	Corp.	Votes			Weights	Corp.	Votes			Weights
	1^{st}	2^{nd}	3^{rd}			1^{st}	2^{nd}	3^{rd}			1^{st}	2^{nd}	3^{rd}	
FOT					Technology					SCM				
CFSC	1	0	11	0.290	CFSC	1	5	6	0.306	CFSC	2	8	2	0.326
CSC	6	5	1	0.356	CSC	8	3	1	0.371	CSC	5	0	7	0.331
JSSC	5	7	0	0.354	JSSC	3	4	5	0.323	JSSC	5	4	3	0.343
MAO					OTF					IMS				
CFSC	1	4	7	0.301	CFSC	0	2	10	0.284	CSC	1	5	6	0.305
CSC	1	6	5	0.308	CSC	3	7	2	0.333	CFSC	10	0	2	0.383
JSSC	10	2	0	0.391	JSSC	9	3	0	0.383	JSSC	1	7	4	0.312
VST					CQ					LSC				
CFSC	5	3	4	0.340	CFSC	0	3	9	0.289	CFSC	0	3	9	0.288
CSC	5	2	5	0.337	CSC	8	3	1	0.371	CSC	8	4	0	0.375
JSSC	2	7	3	0.323	JSSC	4	6	2	0.340	JSSC	4	5	3	0.337
FMP					OP					SDC				
CFSC	6	5	1	0.344	CFSC	2	1	9	0.302	CFSC	0	6	6	0.297
CSC	5	2	5	0.325	CSC	1	10	1	0.323	CSC	10	2	0	0.391
JSSC	1	5	6	0.331	JSSC	9	1	2	0.375	JSSC	2	4	6	0.312
CO					IP					CR				
CFSC	2	3	7	0.309	CFSC	2	10	0	0.335	CFSC	2	1	9	0.302
CSC	1	6	5	0.308	CSC	5	0	7	0.329	CSC	2	7	3	0.323
JSSC	9	3	0	0.383	JSSC	5	2	5	0.336	JSSC	8	4	0	0.375
RRC					CCS					DC				
CFSC	0	3	9	0.290	CFSC	1	10	1	0.323	CFSC	0	7	5	0.298
CSC	8	2	2	0.367	CSC	4	0	8	0.320	CSC	12	0	0	0.407
JSSC	4	7	1	0.343	JSSC	7	2	3	0.357	JSSC	0	5	7	0.295
SOI														
CFSC	4	2	6	0.327										
CSC	6	4	2	0.353										
JSSC	2	6	4	0.320										

(4) Step 4: Calculate the Weights

(a) Weights of the criteria and sub-criteria

TF use the votes of Table 3-7 to calculate the weights of the seven criteria by model (3-3). Figure 3-3 shows that the weights for culture, management, technology, quality, price, material and flexibility at the first level are 0.873, 0.912, 1.000, 0.829, 0.716, 0.679 and 0.698, respectively. After normalizing these data, the weights of outcome are 0.153, 0.160, 0.175, 0.145, 0.125, 0.119 and 0.122, respectively. Similarly, TF use the votes of Table 3-8 and the same procedure to determine the weights of the sub-criteria. The weights of sub-criteria are listed in columns 5 and 10 of Table 3-8.

(b) Weights of shipbuilding corporations

TF use the votes of Table 3-9 to calculate the weights of the three corporations for the specific sub-criteria, using the same methodology. TF derive the weights of shipbuilding corporations CFSC, CSC and JSSC which added up to one, as shown in columns 5, 10 and 15 of Table 3-9.

(5) Step 5: Ranking of Shipbuilding Corporations

This step required the managers to assess the performance of all the shipbuilding corporations within the nineteen sub-criteria of the second level identified as important for corporations rating. In the first row of Table 13-10, the number 0.069 is equal to the "Culture" criterion score 0.153 product the "FOT" sub-criterion score 0.45. And then, TF use the same way to get other results. Once the weights for sub-criteria have been determined, it is relatively easy to calculate the resulting corporations rating scores. The rating value for each corporation was obtained by summing the products of the respective elements. Finally, TF calculate the scores for sub-criteria by the weights of the corporations to get the total weighted scores shown at the bottom of Figure 3-3. And the corporations CFSC, CSC and JSSC get the total weighted scores of 0.308, 0.349 and 0.343 in the last row of Table 3-10. This gives a rating score for each corporation, the higher is the rating and the better is the corporation's performance.

Table 3-10: Rating of three shipbuilding corporations

Criteria (A)	Sub-criteria (B)		Weights (C= A×B)	Scores			Weighted Scores		
				CFSC (D)	CSC (E)	JSSC (F)	CFSC (C× D)	CSC (C×E)	JSSC (C×F)
Culture	FOT	**0.450**	**0.069**	0.290	0.356	0.354	0.020	0.025	0.024
0.153	MAO	0.359	0.055	0.301	0.308	0.391	0.017	0.017	0.021
	VST	1.191	0.029	0.340	0.337	0.323	0.010	0.010	0.009
Management	FMP	0.281	0.045	0.344	0.325	0.331	0.015	0.015	0.015
0.160	CO	0.264	0.042	0.309	0.308	0.383	0.013	0.013	0.016
	RRC	0.226	0.036	0.290	0.367	0.343	0.010	0.013	0.012
	SOI	0.230	0.037	0.327	0.353	0.320	0.012	0.013	0.012
Price	IP	0.504	0.063	0.335	0.329	0.336	0.021	0.021	0.021
0.125	CCS	0.496	0.062	0.323	0.320	0.357	0.020	0.020	0.022
Quality	OTF	0.351	0.051	0.284	0.333	0.383	0.014	0.017	0.019
0.145	CQ	0.331	0.048	0.289	0.371	0.34	0.014	0.018	0.016
	OP	0.318	0.046	0.302	0.323	0.375	0.014	0.015	0.017
Material	SCM	0.304	0.036	0.326	0.331	0.343	0.012	0.012	0.012
0.119	IMS	0.339	0.040	0.305	0.383	0.312	0.012	0.015	0.013
	LSC	0.357	0.042	0.288	0.375	0.337	0.012	0.016	0.014
Flexibility	SDC	0.285	0.035	0.297	0.391	0.312	0.010	0.014	0.011
0.122	CR	0.350	0.043	0.302	0.323	0.375	0.013	0.014	0.016
	DC	0.366	0.045	0.298	0.407	0.295	0.013	0.018	0.013
Technology		1.000	0.175	0.306	0.371	0.323	0.054	0.065	0.057
0.175									
Total Weighted Scores							**0.308**	**0.349**	**0.343**

(6) Step 6: Selection of Shipbuilding Corporations

According to the DM1, the main advantage of this methodology is that it can help them to think in a comprehensive and detailed manner, while allowing them to categorize the various issues. The CSC is the largest in the CFSC and JSSC. The CFSC is an organization that is similar in size to company JSSC. Although, the rating value for each corporation was obtained the final score and the ranking of corporation CSC, JSSC and CFSC is first, second and third, respectively. However, we find that JSSC is better than CSC for the criteria of culture, quality, price and management. The CSC company beyond the others because it has a strength competence that is material, flexibility and technology domain, as shown in Table 3-11. Especially, the weights of CSC are more 0.008 than that of JSSC in the technology index. For both of the shipbuilding corporations, the difference of scores will change the final rank. These results will be regarded as sensivity analysis for three shipbuilding corporations.

Table 3-11: Rating of three shipbuilding corporations for seven criteria

Criteria	Shipbuilding Corporations			Criteria	Shipbuilding Corporations		
	CFSC	CSC	JSSC		CFSC	CSC	JSSC
Culture	0.047^3	0.052^2	0.054^1	Price	0.041^2	0.041^2	0.043^1
Management	0.050^3	0.052^2	0.054^1	Material	0.036^3	0.043^1	0.039^2
Technology	0.054^3	0.065^1	0.057^2	Flexibility	0.036^3	0.045^1	0.041^2
Quality	0.042^3	0.050^2	0.052^1				

* 0.047^3: "0.047" is a weight and "3" is a rank for three shipbuilding corporations.

3.5 Discussion

Like AHP, the VAHP assessment method for selecting suppliers starts a hierarchy of objectives. The top of the hierarchy provides the analytic focus in terms of a problem statement. This is usually followed by a list of the criteria for each of the foregoing considerations. Depending on how much detail is called for in the model, each criterion may then be broken down into individual parameters whose values are either estimated or determined by measurement or experimentation. The bottom level of the hierarchy contains the alternatives or scenarios underlying the problem.

In AHP, the step is carried out by using paired comparisons between the factors to develop the relative weights. The scale is supposedly "fundamental" in the mind, yet there is no rule for how a transformation to such a scale occurs. A person's transformation of a set of weights to fundamental scale could change over time. And the approach is basically qualitative and difficult to judge, it is arguably more burdensome to implement from both data requirement and validation point of view than by using the voting ranking.

In summary, the comparisons between VAHP and AHP are:

(1) The VAHP method is simple to understand and use for getting priority or weights. All experts were given the opportunity to examine the priority weights calculated from their initial responses and to assess the reasonableness of the ranking. When their result seemed

counterintuitive, they were encouraged to reevaluate their input data, determine the source of the inconsistency and make the appropriate changes.

(2) The VAHP's information for decision-maker is the same as AHP and facilitates communication of the problem and solution recommendation.

(3) The VAHP method provides "vote-ranking" rather than "paired comparison" quantifying and measuring consistence. The paired comparison is used to weight the criterion in the AHP is more difficult than the vote-ranking which is used in the VAHP.

(4) The disadvantage of VAHP that each candidate is permitted to choose the most favorable weights to be applied to his/her standings. That causes the difference of scores too small to reflect the real gap of the evaluated result. However, we calculate the ranking of the results that is not affected.

(5) The strongest features of the AHP are that it generates numerical priorities from the subjective knowledge expressed in the estimates of paired comparison matrices. In this study we use the vote-ranking, to determine the weights in the selected rank, in place of paired comparison method. In the six-step procedure, the difference between VAHP and AHP is in step 3 and step 4 of Table 3-12.

Table 3-12: Difference of the comparison between VAHP and AHP

Steps	AHP	VAHP
1	Define criteria and sub-criteria	Define criteria and sub-criteria
2	Structure the hierarchy of the objective	Structure the hierarchy of the objective
3	*Determining the Comparison matrix*	*Priority votes of criteria or sub-criteria*
4	*Calculating the weights* (*Eigenvalue*)	*Calculating the weights* (*Vote-ranking*)
5	Measure objective performance	Measure objective performance
6	Decision-making of objective priority	Decision-making of objective priority

4. SELECTING MULTIPLE SUPPLIERS FOR A SUPPLY CHAIN

4.1 Introduction

The increasingly competitive global business environment not only requires more efficient use of supply chain resources to coordinate geographically dispersed manufacturing and marketing activities, but also makes supply chain efficiency. Suppliers in a supply chain perform interactively rather than independently, as the output of one organization can be the input of another. Consequently, all decisions should be integrated by trading off the performances of different suppliers at each supply chain stage.

Assume that a firm wishes to select several suppliers from a pool of candidates. A composite supplier (CS) composes a subset of suppliers. For each of these areas, particular performance dimension was subjectively selected for comparison. The performance increases in all of the to-be-maximized indices; that is, a higher measure value indicates superior performance for the dimension being under consideration. Unlike the to-be-maximized indices, for the to-be-minimized indices a lower value translates into superior performance for the dimension being considered. No preference weights exist among the indices.

For a CS, the value of an index equals the sum of the values of the suppliers of which the CS composed. This investigation employs DEA to assess the relative (not absolute) performance of each CS against all of the others. DEA identifies efficient and inefficient CSs' and allowing an efficient CS to be selected based on further analysis. This investigation also performed sensitivity analysis to obtain the lower and upper bounds for each candidate index value given that the obtained set of efficient CS remained unchanged.

4.2 Method

Liu and Hai (2000) develop a procedure with six steps to determine a supply chain partners. A numerical illustrative example is used as follow.

4.2.1 Step 1: Find Suppliers of Supply Chain

Define the group of suppliers being evaluated. The suppliers being evaluated should be supplying same goods or services, and several of them should be chosen. The illustrative example considers five candidate suppliers (S1, S2, S3, S4 and S5).

4.2.2 Step 2: Define Performance Indices

For suppliers or customers, maximizing value added to products and satisfying users has become more important and non-value-adding activities should be eliminated as much as possible so that uncertainty, time and cost will be reduced. Defining the inputs and outputs of suppliers' indices for evaluation is the first step. The input and output indices should be well defined and collectable.

(1) The inputs (cost and delivery)

Cost: The most direct reflection of supply chain performance is the actual cost incurred to accomplish specific operating objectives. Cost expectations are the essence of the budgeting process discussed earlier. Supply chain cost performance is typically measured in terms of total dollars, as a percentage of sales, or as a cost per unit of volume. The index cost is the lowest total cost required to achieve the logistics through efficient operations, technology and/or scale economies. The costs include those related to order fulfillments, total inventory carrying, logistics-related finance and management information systems and production labor and inventory overhead costs.

Delivery: It measures whether an order proceeds smoothly through every step-order entry, credit clearance, inventory availability, accurate picking, on-time delivery, correct invoicing and payment without deductions-of the order management process without fault, be it expediting or exception processing. Form an operational perspective, a multi-industry consortium defines the perfect delivery as one that meets all the following standards: (1) complete delivery of all items requested. (2) According to customer's request date, deliver with one-day tolerance. (3) Complete and accurate document supporting the order, including packing slips, bills of lading and invoices; and (4) perfect condition, that is, faultlessly installed, correct configuration, customer-ready with no damage. The index delivery measures the ability of the firm to respond to customer demands.

(2) The outputs (flexibility and quality)

Flexibility: The supplier should give valid capability within the range of conditions that the firm might experience. It should have the ability to be easily modified, or to be self-adjusting response to change in the firm's environment; for example, tax laws change and new technological advancements alter risk levels. The index *flexibility* is the ability to handle difficult, non-standard orders to meet special customer specifications and supply products characterized by numerous features, options, service requests, colors, order size and/or volume or composition during logistics. Flexibility also frees supplier firms from rigid, engaging and long-term agreements, enhancing their freedom to adapt to changing circumstances.

Quality: Quality measures, which are the most process-orientated evaluations, are designed to determine the effectiveness of a series of activities rather than an individually activity. However, quality is usually difficult to measure because of its broad scope. These quality performance measures include frequency of damage, dollar amount of damage, number of customer returns, and cost of returned goods. The index *quality* describes the ability to meet product and service quality requirements and permits the customer to weigh the specific categories of each quality component using individualized overall satisfaction ratings. The data will reflect which areas of quality are highly rated by customers, and which are perceived as unsatisfactory.

4.2.3 Step 3: Collect the Data of Suppliers

The data of each index is either subjective or non-subjective. Subjective data is collected through surveys or questionnaires of individuals who participated in the supply activities, while non-subjective data is obtained from historical records. In the illustrative example presented here, the values of cost, delivery and quality of each supplier are the category of non-subjective data. One could collect existing suppliers' data from their record or could ask the new candidate to provide the data. For every supplier delivery time, the function reaches its minimum value if the delivery of orders is completed on time. Otherwise, a penalty is imposed which (at different rates) according the delay and early delivery time. Formally, for each supplier j, D_j is the planned delivery time, D_j is the actual delivery time, and the penalty function is defined as follow:

$$C(D_j)=\begin{cases}0, & \text{if } D_j = d_j \\ \alpha\, C_j, & \text{if } D_j < d_j \\ \beta\, C_j, & \text{if } D_j > d_j\end{cases} \tag{4-1}$$

Same definition is applied to quality index, Q_j is the standard quality level q_j is the actual quality level, and the penalty function (buyer's quality lost cost) is defined as follow:

$$C(Q_j)=\begin{cases}0, & \text{if } Q_j \le q_j \\ \gamma\, C_j, & \text{if } Q_j < q_j\end{cases} \tag{4-2}$$

where α, β, and γ are constants

Supplier flexibility is a subjective index in the perspective of the manufacture. Subjective indices could be translated into numerical ratings using different methods, such as questionnaire, AHP and so on. Managers may ask their colleagues to answer questionnaires to rate the flexibility of each supplier. Table 4-1 lists the example for rating the subjective index, where the lower and upper bounds are predetermined. The average rating can be taken as the data for each supplier. Since flexibility should be maximized, the least-favorable candidate is assigned the smallest value and the most-favorable candidate is assigned the largest value. Meanwhile, for to-be-minimized indices that are to be minimized, the least-favorable candidate is assigned the largest value and the most-favorable candidate is assigned the smallest value (Ram et al., 2001). The range of subjective indices is set between 1 and 9. Table 4-2 lists the collected raw data.

Table 4-1: Rating scale of subjective indices

Scores	Grades	Descriptions
9	Excellence	Demonstrates substantially excellence performance, has been in the excellence for last one year.
7	Good	The performance has a good market image, it fills a real need and is seen by the customers as comparable to existing good company.
5	Acceptable	Meet minimum standard requirement.
3	Need attention	Overall performance does not meet officers and customer minimum acceptance level.
1	Poor	Overall performance is well below officers and customer acceptance level, is inferior to vast majority of suppliers.

Table 4-2: The collected data of suppliers

Suppliers	Inputs		Outputs	
j	c_j	d_j	f_j	q_j
1	30000	2400	3.9	1053
2	40000	3000	3.1	1250
3	35000	1500	2.8	1538
4	22000	900	4.7	1887
5	29000	2100	4.2	2632

* f_j is average score while q_j, c_j, and d_j are dollars.

4.2.4 Step 4: Correspondence of DCU and DMU

For example, the cost of supplier S1 (DCU=(1,0,0,0,0)) adds supplier S2 (DCU=(0,1,0,0,0)) in supplier S1 + supplier S2 (70000, DCU=(1,1,0,0,0)). Besides, we will get the different combination results on this way when we consider the other indices like delivery, flexibility and quality. In the process, the total number of possible DCUs equals 32 when the examples involve five suppliers in model (2-1). Table 4-3 lists the 32 DCUs and DMUs.

Table 4-3: The correspondence of DCU and DMU

j	DCU_j					DMU_j				j	DCU_j					DMU_j			
	w_1	w_2	w_3	w_4	w_5	c_j	d_j	f_j	q_j		w_1	w_2	w_3	w_4	w_5	c_j	d_j	f_j	q_j
0	0	0	0	0	0	---	---	---	---	16	0	0	0	0	1	29000	2100	4.2	2632
1	**1**	**0**	**0**	**0**	**0**	**30000**	**2400**	**3.9**	**1053**	17	1	0	0	0	1	59000	4500	8.1	3685
2	**0**	**1**	**0**	**0**	**0**	**40000**	**3000**	**3.1**	**1250**	18	0	1	0	0	1	69000	5100	7.3	3882
3	1	1	0	0	0	70000	5400	7.0	2303	19	1	1	0	0	1	99000	7500	11.2	4935
4	0	0	1	0	0	35000	1500	2.8	1538	20	0	0	1	0	1	64000	3600	7.0	4170
5	1	0	1	0	0	65000	3900	6.7	2591	21	1	0	1	0	1	94000	6000	10.9	5223
6	0	1	1	0	0	75000	4500	5.9	2788	22	0	1	1	0	1	104000	6600	10.1	5420
7	1	1	1	0	0	105000	6900	9.8	3841	23	1	1	1	0	1	134000	9000	14.0	6473
8	0	0	0	1	0	22000	900	4.7	1887	24	0	0	0	1	1	51000	3000	8.9	4519
9	1	0	0	1	0	52000	3300	8.6	2940	25	1	0	0	1	1	81000	5400	12.8	5572
10	0	1	0	1	0	62000	3900	7.8	3137	26	0	1	0	1	1	91000	6000	12.0	5769
11	1	1	0	1	0	92000	6300	11.7	4190	27	1	1	0	1	1	121000	8400	15.9	6822
12	0	0	1	1	0	57000	2400	7.5	3425	28	0	0	1	1	1	86000	4500	11.7	6057
13	1	0	1	1	0	87000	4800	11.4	4478	29	1	0	1	1	1	116000	6900	15.6	7110
14	0	1	1	1	0	97000	5400	10.6	4675	30	0	1	1	1	1	126000	7500	14.8	7307
15	1	1	1	1	0	127000	7800	14.5	5728	31	1	1	1	1	1	156000	9900	18.7	8360

4.2.5 Step 5: Evaluate DMUs by DEA Model

DEA provides relative (not absolute) rankings of supply chain component performances. We use the mathematical programming software package CPLEX running on personal computer to solve (2-5) and (2-8) models. The results are listed in Table 4-4.

Table 4-4: Efficiency results

j	DCU_j					CCR	BCC	RTS	j	DCU_j					CCR	BCC	RTS
	w_1	w_2	w_3	w_4	w_5					w_1	w_2	w_3	w_4	w_5			
0	0	0	0	0	0	---	---	---	16	0	0	0	0	1	1.47	1.15	DRS
1	**1**	**0**	**0**	**0**	**0**	1.22	**1.00**	DRS	17	1	0	0	0	1	1.56	1.11	DRS
2	**0**	**1**	**0**	**0**	**0**	1.67	1.03	DRS	18	0	1	0	0	1	2.02	1.18	DRS
3	1	1	0	0	0	2.14	1.001	DRS	19	1	1	0	0	1	1.89	1.10	DRS
4	0	0	1	0	0	1.52	**1.00**	DRS	20	0	0	1	0	1	1.95	1.25	DRS
5	1	0	1	0	0	2.07	1.05	DRS	21	1	0	1	0	1	1.84	1.12	DRS
6	0	1	1	0	0	2.72	1.11	DRS	22	0	1	1	0	1	2.20	1.23	DRS
7	1	1	1	0	0	2.29	1.05	DRS	23	1	1	1	0	1	2.04	1.09	DRS
8	0	0	0	1	0	**1.00**	**1.00**	CRS	24	0	0	0	1	1	1.22	**1.00**	DRS
9	1	0	0	1	0	1.29	**1.00**	DRS	25	1	0	0	1	1	1.35	**1.00**	DRS
10	0	1	0	1	0	1.70	1.06	DRS	26	0	1	0	1	1	1.62	1.09	DRS
11	1	1	0	1	0	1.68	**1.00**	DRS	27	1	1	0	1	1	1.63	**1.00**	DRS
12	0	0	1	1	0	1.62	1.004	DRS	28	0	0	1	1	1	1.57	**1.00**	DRS
13	1	0	1	1	0	1.63	**1.00**	DRS	29	1	0	1	1	1	1.59	**1.00**	DRS
14	0	1	1	1	0	1.95	1.08	DRS	30	0	1	1	1	1	1.82	1.08	DRS
15	1	1	1	1	0	1.87	**1.00**	DRS	31	1	1	1	1	1	1.78	**1.00**	DRS

4.2.6 Step 6: Output Results

As shown in Table 4-4, DMU_9 is efficient, indicating that the associated DCU_9, (1,0,0,1,0), in Table 4-5 where suppliers S1 and S4 are selected, is an efficient composite. Table 4-5 rearranges the 13 efficient DCUs according to the number of suppliers selected.

We use different metrics to evaluate the performance of the entire supply chain, individual members or subsets of members. We will get some efficient-frontier suppliers in 32 alternative options from four performance indices of the five suppliers. These efficient DMUs like as single supplier: S1 (*j*=1), S3 (*j*=4) and S4 (*j*=8), two combination of suppliers: S1 and S4 (*j*=9), S4 and S5 (*j*=24).

Table 4-5: Efficient supplier composites

Efficient DCUs	Supplier composites
DCU_1, DCU_4, DCU_8	(S1), (S3), (S4)
DCU_9, DCU_{24}	(S1, S4), (S4, S5)
DCU_{11}, DCU_{13}, DCU_{25}, DCU_{28}	(S1, S2, S4), (S1, S3, S4), (S1, S4, S5), (S3, S4, S5)
DCU_{15}, DCU_{27}, DCU_{29}	(S1, S2, S3, S4), (S1, S2, S4, S5), (S1, S3, S4, S5)
DCU_{31}	All

DEA providers “a measure of efficiency” of each DMU is allowed, in particular, to separate efficient from inefficient DMUs. They will provide various alternatives to make decision from efficient DMUs. In the category of single supplier, S1 or S4, respectively, have the highest to-be-maximized performance flexibility and quality, while S4 has the lowest to-be-minimized performance cost and delivery. In the two supplier categories, the pair of S1 and S4 is not the only choice, and the pair of S4 and S5 would be selected as SC suppliers if cost or flexibility was the key consideration. Meanwhile, if only one supplier is being selected, one DEA model can be directly chosen to assess the performance of each supplier and select one of the efficient suppliers. If the final decision permits multiple suppliers, the novel MOBILP approach provides more options. For various reasons, selections can differ among firms. Table 4-6 lists the composites of the to-be-minimized and to-be-maximized indices of the two suppliers.

Table 4-6: The composites data of two suppliers

Suppliers	To-be-minimized		To-be-maximized	
	Cost	Delivery	Flexibility	Quality
S1 and S4	(30000, 22000)	(2400, 900)	(3.9, 4.7)	(1053, 1887)
S4 and S5	(22000, 29000)	(900, 2100)	(4.7, 4.2)	(1887, 2632)

4.3 Sensitivity Analysis

The data for each supplier, listed in Table 4-2, may be questioned. For example, investigators can examine the extent to which perturbation in the data can be tolerated before the current DEA efficiency is changed as inefficient. Sensitivity analysis was conducted for cost and delivery variations one at a time. For every supplier under consideration, cost and delivery are increased stepwise in 5% increments, while and flexibility and quality are decreased by 5% decrements. This process is continued with 5%+ (5%-) cost and delivery increments (quality and flexibility decrements) up to 30%+ (30%-). (Thompson et al., 1997)

We use the data of Table 4-3 to solve model (2-8). Table 4-7 listed the step changes for the current DEA efficiency. For example, the first data of the Quality column, $.95q_1$ indicates that the downward perturbation of q_1 stops at the step of .95, since DMU_4 becomes an inefficient DMU. DMU_4 is more sensitive than any other in the supplier process. It becomes an inefficient DMU when its quality and delivery are downward or upward at the step of +5% or -5%. The DMUs 1, 8, 9, 25, 29 and 31 will not change efficiency frontier.

Table 4-7: The sensitivity analysis results

Status	DMUs	Quality	Flexibility	Cost	Delivery
EFFICIENT	1				
	4	**.95 q_1**, .95 q_5, .9 q_4, 1.05 q_3			.95 d_1, .9 d_5, 1.05 d_4
	8				
	9				
	11		.7 f_2		
	13	.85 q_5, 1.15 q_3	.9 f_3, 1.1 f_5		1.25 d_3
	15	.85 q_5, 1.15 q_3	.85 f_3, 1.15 f_5		
	24		.8 f_5, 1.25 f_1		
	25				
	27	.75 q_3	.8 f_2, 1.15 f_3	.7 c_3	
	28		.85 f_3, .8 f_5, 1.15 f_1		.85 d_1, 1.15 d_3
	29				
	31				

In the management context, changes are made in upward and downward steps of +5% and -5%, respectively, a scale of change that can be accepted by managers. Upward and downward changes of any proportion for the to-be-minimized and to-be-maximized indices can also be examined. This result captures differences in the competition indices of suppliers that allow them to rapidly respond to the dynamic environment. The production functions derived can be used for forecasting and sensitivity analysis, providing useful insights into policy decisions. In their tolerance, the managers will change the to-be-minimized values or to-be-maximized values to realize all the suppliers. These results can be used to enhance and alter decisions.

The actual competitiveness of the supply chain will be determined by the ability to develop successful partnerships. The implications for supply chains will be a diversity of partnerships characterized by an enhanced asset specificity and higher exit and entry barriers. Finally, in this dissertation, we use DEA in the application of MOBILP about how to find strategic alliance for these individual DMUs. The idea of using DEA to select suppliers will be listed in Figure 4-1.

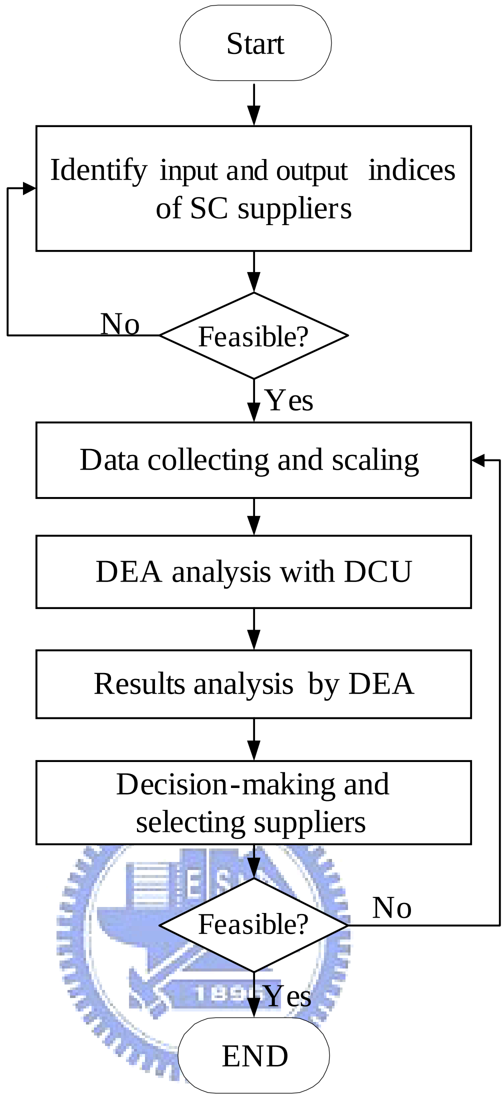

Figure 4-1: Flow chart for selecting suppliers with DEA

5. CONCLUSIONS AND SUGGESTIONS

The issues of supplier selection always emerge due to the following characteristics of supply chain. Firstly, they are subjected to frequent changes - new suppliers, new buyers, new types of products appear frequently and the supply chain networks should be adjusted according to the changes by adopting new members dynamically. Secondly, although it is well-known that sharing information among supply chain members can lead to improved efficiency, information sharing is not always possible, often because of the limitations in information systems, too frequent changes in partnerships, or strategic reason resulting from game-theoretic behavior of companies-information sharing is especially difficult between companies that are remotely located in the supply chain topology in contrast to neighboring companies. Thirdly, controlling and coordinating production and orders of supply chain members by a single company are in many cases unfeasible, because supply chain members are usually independent companies.

This dissertation presents two novel methods for selecting suppliers by VAHP and MOBILP. Suppliers of multiple types of products may be considered, and each candidate may supply multiple products, while each product can also be supplied by multiple suppliers. Some further research issues addressed are summarized below. These issues include advantages and suggestions of using VAHP or MOBILP to select suppliers.

5.1 Conclusions

These advantages include:

(1) DEA can simultaneously utilize multiple outputs and inputs with each being stated in different units of measurement. It will not require specification or knowledge of a prior weights or prices for the inputs or outputs.

(2) Using DEA on best-practice frontiers rather than on central-tendency properties of frontiers satisfies strict equity criteria in the relative evaluation of each DMU. Organizations increase productivity either by increasing outputs while holding inputs constant or by decreasing inputs while maintaining constant outputs. Managers are thus free to compute the efficient supply chain performance use of various factors of production (i.e., inputs) to create results (i.e., outputs) that the DMU deems as valuable.

(3) For the VAHP approach, it allows the managers to generate non-inferior options and systematically analyze the inherent tradeoffs among the relevant criteria. We discuss so far applicability of the ranking method and DEA, and determine the weights from rank voting data. Then we show that the total ordinal rank of objects may produce a different result according to the difference of the weights between ranks.

(4) We use MOBILP to identify a series of various strategic combinations for individual DMUs that will allow them to be aggregated. We will obtain performance measurement of different combinative options.

5.2 Suggestions

Other suggestions and further research issues include:

(1) In VAHP, it is expected that, in the near future, this method will be applied effectively to various issues such as employee selection, policy making, business strategies and performance assessment. Next, the ranking method of alternatives, it can't relatively be convincing and is difficult to determine suitable weights of each alternative. We can consider and use more scientific method to collect ranking data like fuzzy data or utility function.

(2) In VAHP, some different constraints shall be added to the related model in real competition markets. Meanwhile, the supplier k must set w_k =1 or else there will only be one choice between the specific two suppliers, G and H, and $w_G + w_H$ =1.

(3) The MOBILP method could be extended to become a management and strategic tool, particularly in decisions combining various aspects such as mergers, alliances and transportation networks. Next, there is a property of "additive" factor will be considered before strategic alliance agreement can be reached. Therefore, it is very difficult to collect these data when using this method. In addition to these data for supplier selection, more information that is individual has not been considered, such as corporate culture, corporate vision and market structure.

(4) In model (3-3), it did not consider non-increasing weights ratios constraint. If the first place is regard as more important than the second place. Similarly, the second place is more important than the third place. The progressive non-increasing weight ratio, we will add the constraint $(u_{l1}/u_{l2}) \geq (u_{l2}/u_{l3}) \geq \ldots \geq (u_{l,E-1}/u_{lE})$.

In the non-increasing weights ratios vote-ranking method, model (5-1) ensures the ratios between weights are non-increasing in the order. We can apply the constraint condition at the Olympics (Condon et al., 1999; Lozano et al., 2002; Lins et al., 2003; Villa & Lozano, 2004; Liu & Hai, 2005b, 2006c). In the results, they can get real responses that winning a gold medal is more difficult than winning a silver medal and winning a silver medal is more difficult than winning a bronze medal. We obtain the Non-Increasing Weight Ratio Vote-Ranking Model (NIWR vote-ranking):

$$
\begin{aligned}
\theta_{ll} = \text{Max} \quad & \sum_{e=1}^{E} u_{le} x_{le} \\
\text{s.t.} \quad & \sum_{e=1}^{E} u_{le} x_{pe} \le 1, && p = 1, \ \ldots \ , L; \\
& e\, u_{le} \ge (e+1) u_{l,e+1}, && e = 1, \ \ldots \ , E-1; \\
& \frac{u_{le}}{u_{l,e+1}} \ge \frac{u_{l,e+1}}{u_{l,e+2}}, && e = 1, \ \ldots \ , E-2; \\
& u_{lE} \ge \varepsilon = \frac{2}{gE(E+1)}.
\end{aligned}
\tag{5-1}
$$

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