行政院國家科學委員會專題研究計畫 成果報告

應用多目標選擇規劃於TFT-LCD廠之篩選
研究成果報告(精簡版)

計 畫 類 別 ：個別型
計 畫 編 號 ：NSC 95-2416-H-216-003-
執 行 期 間 ：95年08月01日至96年07月31日
執 行 單 位 ：中華大學工業工程與系統管理學系

計畫主持人：李欣怡

計畫參與人員：博士班研究生-兼任助理：王維民
碩士班研究生-兼任助理：洪筱筑、王淑茹

報 告 附 件 ：出席國際會議研究心得報告及發表論文

處 理 方 式 ：本計畫涉及專利或其他智慧財產權，2年後可公開查詢

中 華 民 國 96年09月27日

行政院國家科學委員會專題研究計畫成果報告(精簡版)

應用多目標選擇規劃於 TFT-LCD 廠之篩選

MULTI-CHOICE GOAL PROGRAMMING APPLIED TO SELECT TFT-LCD COMPANIES FOR DOWNSTREAM MANUFACTURERS

計畫編號：NSC 95-2416-H-216-003
執行期限：95 年 8 月 1 日至 96 年 7 月 31 日
主持人：李欣怡　中華大學工業工程與系統管理學系
計畫參與人員：王維民、洪筱筑、王淑茹

中文摘要：在高度競爭的環境中，一個好的供應鏈是公司免於危機，進而獲利的基礎。在目前，僅有少數較有規模的大公司能夠從開始之設計到最後的配送階段，完成整個供應鏈的垂直整合。而大部分的公司，僅能專注於本身的專業製造上，而必須與上、下游廠商合作並製造生產。因此供給商之選擇，對於企業保持獲利是非常重要的。本研究主要目的在構建多選擇目標規劃以協助下游製造商對上游薄層液晶顯示器(TFT-LCD)供給商的選擇。首先以模糊階層分析法(FAHP)，決定多目標函數的權重，其目標包含如成本、品質、交貨時間、供應商數目等;其次採用多選擇目標規劃考慮各項資源的限制，及構建條件限制式。經由實例測試與驗證可得知，本模式除兼具模糊目標函數、符合決策行為特性需求、考量資源的供應限制，結果顯示可客觀的衡量決策者在模糊多選擇目標下對於TFT -LCD供給商的最佳採購水準。

關鍵詞：多選擇目標規劃、供應商、薄層液晶顯示器、模糊階層分析法、採購

ABSTRACT

A good supply chain relationship is essential for a company to survive and to acquire reasonable profit in today's highly competitive global environment. Only very few large companies can and are willing to vertically integrate from the design stage to the final distribution of the entire supply chain. Most companies focus on their specialized functions and to cooperate with upstream or downstream companies. As a result, supplier selection is important for maintaining a certain degree of strategic alliance. This project aims to develop a fuzzy multi-choice goal programming (FMCGP) model to help downstream companies to select thin film transistor liquid crystal display (TFT-LCD) suppliers for cooperation. First, fuzzy analytic hierarchy process (FAHP) is applied to analyze the importance of multiple factors by incorporating experts' opinion. Next, multi-choice goal programming is used to consider the limits of various resources and to formulate the constraints. From the experimental design and examination, we testify that the proposed model not only can consider multi-choice goals, decision making behavior and limit of resources, but it can also allocate the purchase among the selected supplier(s).

KEY WORDS

Supplier selection, Performance, TFT-LCD, Multi-choice goal programming, Fuzzy analytic hierarchy process

1. Introduction

The TFT-LCD supply chain involves the domains of optics, semiconductor, electrical engineering, chemical engineering, mechanical engineering and material. Because a wide variety of technologies are required from the upstream to the downstream in the supply chain, very few companies have the capability and are willing to cover all operations from the making of material to the manufacturing of final products in the supply chain. Therefore, division of works and cooperation among companies are necessary in the TFT-LCD industry. The TFT-LCD supply chain is usually segregated into three parts: upstream, midstream and downstream. The upstream includes the equipment (e.g. photo/etch equipment) and the material and components (e.g. glass substrate, backlight module and driver IC). By using the equipment provided by equipment suppliers and the material provided by the material/components suppliers, the midstream companies first manufacture panels and then assembled them into TFT-LCD modules. Downstream manufacturers use the modules to make final products such as notebook computer, LCD monitors, etc.

Outsourcing has become an important business approach in various industries since a competitive advantage may be gained by cooperating with suppliers to provide products/services more effectively and efficiently [1]. Companies in a TFT-LCD supply chain usually focus on only one or two steps in the supply chain while outsourcing the rest of steps to other companies. For instance, a TFT-LCD manufacturing company may receive orders from a notebook manufacturing company, which specifies the specification of the panels, and manufacture TFT-LCD modules according to the design. It also needs to find upstream companies to obtain the required equipment, material and components. On the other hand, for a notebook manufacturing company, it also needs to find one or several suitable TFT-LCD manufacturing companies to obtain the required TFT-LCD module for further producing notebook computers. In consequence, the selection of the right companies for cooperation is important for maintaining a competitive edge. In addition, how to distribute the amount of purchases to the selected manufacturers is also a problem faced by the purchasing companies.

The rest of this report is organized as follows. Section 2 reviews some recent researches on supplier selection. FAHP and goal programming are discussed in Section 3. Section 4 proposes a FMCGP model applied to select TFT-LCD companies by downstream manufacturers. Some concluding remarks are made in the last section.

2. Supplier Selection Problem

In current business environment, global competition is inevitable, and customer demands are diversified. This results in progressively increased costs and sharply decreased profit. Therefore, purchasing has become a crucial job in establishing value-added contents of products and a vital determinant to ensure the profitability and survival of a company. Many companies are trying to reduce their costs while satisfying customer needs by strengthening their core competencies and outsourcing other functions. Suppliers have varied strengths and weaknesses; thus, supplier selection requires a careful assessment in order to maintain a continuous good buyer-supplier relationship.

Categorical method is the simplest supplier selection method. Each supplier characteristic is assigned good, satisfactory, neutral and unsatisfactory and then the total score for each supplier is summed up [2]. Linear weighing method is one of the most common methods, and the concept is to give different weights to a number of criteria and to select the supplier with the best weighted total score [3]. Although most proposed methods belong to linear weighting and mathematical programming (MP) models [4], MP models are proved more effective than the linear weighting methods because they can optimize the explicitly stated objective [5]. Muralidharan *et al.* [6] did a comparison of various supplier rating methods and listed the advantages and limitations of the methods.

A MP model formulates the decision problem in terms of a mathematical objective function that needs to be maximized (e.g. profit) or minimized (e.g. cost) by varying the values of variables in the objective function (e.g. the amount ordered with a supplier) [4]. Most-used MP models in supplier selection are linear programming, mixed integer programming, and goal programming/multi-objective goal programming (MOP). Weber and Desai [7], Weber *et al.* [8] and Muralidharan *et al.* [6] reviewed past supplier selection researches by MP models. Hong *et al.* [4] proposed a mathematical programming model that considers the change in suppliers' supply capabilities and customer needs over a period in time, and the model not only can maximize revenue but also can satisfy customer needs. Multi-objective programming (MOP) is a very popular tool since many criteria, not a single criterion, can be examined with different weights. Weber and Current [9] introduced a MOP for selecting suppliers with order quantities in procurement environments characterized by multiple conflicting criteria. Weber (1996) applied DEA in supplier evaluation for an individual product and demonstrated the advantages of applying DEA.

Two or more methodologies can be combined in the evaluation of suppliers. Ghodsypour and O'Brien [2] combined AHP and linear programming to choose the best supplier and to assign the optimum order quantity among selected suppliers. Weber *et al.* [8] integrated MOP and DEA to deal with non-cooperative supplier negotiation strategies where the selection of one supplier results in another being left out of the solution. Choy *et al.* [11] designed an intelligent supplier relationship management system by using hybrid case based reasoning and artificial neural networks techniques, to select and benchmark potential suppliers. Liu and Hai [12] proposed a voting AHP method, which combined AHP and DEA, for selecting supplier by comparing the weighted sum of the selection number of rank vote, after determining the weights in a selected rank.

3. FAHP and Goal Programming

The AHP is a mathematically based MCDM tool. It is very popular to academic researchers for data analysis and model verifications and to provide critical information for decision makers in various fields such as political, social, economic and management sciences. A complex problem is decomposed into several sub-problems in terms of hierarchical levels, and the factors of the same hierarchical level are compared relative to their impact on the solution of their higher level factor. Pairwise comparisons are employed among decision elements, and comparison matrices are formed. After the consistency of the matrices is examined, the relative weights of decision elements are estimated next. The relative weights are aggregated lastly to obtain an overall rating for the decision alternatives.

Fuzziness and vagueness are common characteristics in many decision-making problems, and a good decision-making model should be able to tolerate vagueness or ambiguity [13]. In addition, decision makers very naturally provide uncertain answers rather than precise values, and it is difficult to transform qualitative preferences to point estimates. Therefore, pairwise comparison under traditional AHP may not be appropriate due to the necessity of selecting arbitrary values in the process, and a degree of uncertainty should be considered in some or all pairwise comparison values [13]. In consequence, the incorporation of the fuzzy theory in AHP should be more appropriate and effective than conventional AHP. Many researches have been done on the development and the application of FAHP, and tremendous amount of FAHP methodologies are existed.

In the last step of FAHP, the total ranking fuzzy numbers for decision elements (e.g. alternatives) are obtained, and the fuzzy numbers need to be ranked. There are many different methods to do the ranking, and each method has its own advantages and disadvantages [14]. Centroid ranking method is a popular way [15]. Let $f_c(x)$ be a membership function for triangular fuzzy number $C=(p,q,s)$, the centroid ranking method formula of triangular fuzzy number *C* is [15]:

$$R(C)=\int x f_C(x)dx \Big/ \int f_C(x)dx \qquad (1)$$

Define $C_i=(p_i,q_i,s_i)$, $i=1,2,...,n$ be n triangular fuzzy numbers. By the formula stated above, one can obtain the centroid rank value of triangular fuzzy number:

$$R(C_i)=\left[\frac{1}{q_i-p_i}\left(\frac{1}{3}q_i^3-\frac{1}{2}q_i^2p_i+\frac{1}{6}p_i^3\right)+\frac{1}{s_i-q_i}\left(\frac{1}{3}q_i^3-\frac{1}{2}q_i^2s_i+\frac{1}{6}s_i^3\right)\right]\Big/\left[\frac{1}{2}(s_i-p_i)\right] \qquad (2)$$

Finally, the centroid rank value of triangular fuzzy numbers is:

$$R(C_i)=\tfrac{1}{3}(p_i+q_i+s_i) \qquad (3)$$

A goal programming (GP) model is useful in dealing with multi-criteria decision problems where the goals cannot simultaneously be optimized. GP allows decision makers to consider several objectives together in finding a set of acceptable solutions and to obtain an optimal compromise. The purpose of GP is to minimize the deviations between the achievement of goals and their aspiration levels [16]. Sharma *et al.* [17] proposed a GP formulation for vendor selection to attain goals pertaining to price, quality and lead-time under demand and budget constraints. Buffa and Jackson [18] also proposed the use of GP for price, quality and delivery objectives to evaluate vendors. An integrated AHP and preemptive goal programming based multi-criteria decision-making (MCDM) methodology is developed by Wang *et al.* [19] to select the best set of multiple suppliers to satisfy capacity constraint.

Determining precisely the goal value of each objective is difficult for decision makers since possibly only partial information can be obtained [20]. Some approaches, such as probability distribution, penalty function fuzzy numbers and various types of thresholds, are used to reformulate the GP models in order to incorporate uncertainty and imprecision into the formulation [20]. Narasimhan [21] was the first to propose fuzzy goal programming (FGP) by using the fuzzy set theory with preference-based membership function to GP. Since then, many achievements have been made in areas of preemptive FGP, weight additive model and stochastic model [16].

Kim and Whang [22] investigated the application of tolerance concepts to goal programming in a fuzzy environment by formulating a FGP problem with unequal weights as a single linear programming problem with the concept of tolerance. The model could reflect the decision maker’s view on subjective fuzzy business goals based on his/her experience or intuition. Chen and Tsai [20] formulated FGP by “incorporating different importance and preemptive priorities by using an additive model to maximize the sum of achievement degrees of all fuzzy goals.” The approach allowed the decision maker to determine a desirable achievement degree for each fuzzy goal and to reflect explicitly the relative importance of these goals. Kumar *et al.* [5] presented a fuzzy goal programming approach that considered multiple objectives and dealt with some of the parameters that were fuzzy in nature.A fuzzy mixed integer goal programming was formulated. Three primary goals are minimizing the net cost, minimizing the net rejections, and minimizing the net late deliveries, while the constraints are regarding buyer’s demand, vendors’ capacity, vendors’ quota flexibility, purchase value of items, budget allocation to individual vendor, etc.

Chang [16] proposed an MCGP approach to solve a multi-choice aspiration level (MCAL) problem, in which decision makers can set more aspiration levels to each goal of the multiple objective decision-making problem to find more appropriate resources so as to reach a higher aspiration level in the initial stage of the solution process. The approach is applicable when there is a goal that can be achieved from some specific aspiration levels (i.e., one goal mapping many aspiration levels) [16].

$$\text{Min } \sum_{i=1}^{n} w_i (d_i^+ + d_i^-) \quad (4)$$

$$\text{s.t. } f_i(X) - d_i^+ + d_i^- = \sum_{j=1}^{m} g_{ij} S_{ij}(B) \quad , i = 1,2,\ldots,n \quad (5)$$

$$d_i^+, d_i^- \geq 0 \quad , i = 1,2,\ldots,n \quad (6)$$

$$S_{ij}(B) \in U_i(x), \quad i = 1,2,\ldots,n \quad (7)$$

$$X \in F \text{ (F is a feasible set)} \quad (8)$$

where d_i is the deviation from the target value g_i; w_i represents the weight attached to the deviation; $d_i^+ = max(0, f_i(X) - g_i)$ and $d_i^- = max(0, g_i - f_i(X))$ are, respectively, over- and under-achievements of the ith goal; $S_{ij}(B)$ represents a function of binary serial number; and $U_i(x)$ is the function of resources limitations.

For something that is more/higher the better in the aspiration levels, the highest possible value of membership function is 1, based on the fuzzy theory [23]. To achieve the maximization of $g_{ij}S_{ij}(B)$, the flexible membership function goal with aspiration level 1 (i.e., the highest possible value of membership function) is used as follows [16]:

$$\frac{g_{ij}S_{ij}(B) - g_{min}}{g_{max} - g_{min}} - d_i^+ + d_i^- = 1 \quad (9)$$

where $g_{\max}$ and $g_{\min}$ are, respectively, the upper and lower bound of the right-hand side (i.e., aspiration levels) of equation (6).

For easy calculation, the fractional form of equation (7) is [16]:

$$\frac{1}{L_i} g_{ij} S_{ij}(B) - \frac{1}{L_i} g_{min} - d_i^+ + d_i^- = 1 \quad (10)$$

where $L_i = g_{max} - g_{min}$.

4. Formulation of fuzzy multi-choice goal programming for TFT-LCD manufacturer selection

In this section, an MCGP model with the incorporation of FAHP is proposed for the selection of TFT-LCD manufacturers by a notebook (NB) manufacturer. The steps can be summarized as follows:

Step 1. Form a committee of experts in NB industry and define the TFT-LCD supplier selection problem. The selection of suitable TFT-LCD manufacturers for a NB company to purchase TFT-LCD modules is essential for the NB company to be successful. With a comprehensive review of literature, consultation with domain experts and consideration of data accessibility, the factors for determining the performance of TFT-LCD companies can be organized.

Step 2. Formulate a questionnaire to compare factors pairwisely in their contribution toward achieving the goal of selecting the best TFT-LCD supplier. Five-point scale is applied, and the opinions of experts are collected and combined into a fuzzy pairwise comparison matrix $\tilde{\boldsymbol{A}}$.

$$\tilde{\boldsymbol{A}} = [\tilde{a}_{i\rho}] = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & 1 & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix},$$

for $i, \rho = 1,2,\ldots n$ (11)

where $\tilde{a}_{i\rho} = (l_{i\rho}, m_{i\rho}, u_{i\rho})$ and $a_{i\rho} \cdot a_{\rho i} \approx 1$,

$l_{i\rho}$: the smallest assigned value among the experts,

$m_{i\rho}$: the largest assigned value among the experts, and

$u_{i\rho}$: the geometric average of the values of all other experts.

Step 3. Check the consistency of the fuzzy matrix and obtain FAHP weight, $\tilde{\boldsymbol{w}}$. Based on Buckley [24] and Csutora and Buckley [25], let $A=[a_{i\rho}]$ be a positive reciprocal matrix, and $\tilde{A}=[\tilde{a}_{i\rho}]$ be a fuzzy positive reciprocal matrix, if A is consistent, then $\tilde{A}$ is also consistent. If $\tilde{A}$ is not consistent, the questionnaire must be modified by the experts. The fuzzy weight $\tilde{w}$ is:

$$\tilde{w}_i=[\tilde{a}_{i1}\otimes\cdots\otimes\tilde{a}_{in}]^{1/n}, \text{ for } i=1,2\ldots n \quad (12)$$

Step 4. Defuzzy $\tilde{w}$ by the centroid method. Each fuzzy number of $\tilde{w}$ is defuzzied to get a best crisp value:

$$\overline{w}_i=(w_{i1}+w_{i2}+w_{i3})/3, \text{ for } i=1,2\ldots n \quad (13)$$

Step 5. Normalize the weights of factors. The weights of the factors are normalized by the following:

$$w_i=\overline{w}_i \Big/ \sum_{i=1}^{n}\overline{w}_i, \text{ for } i=1,2\ldots n \quad (14)$$

Step 6. Set the GP model for the supplier selection. The objective is to maximize the satisfaction of the suppliers, and the goals are $G_1, G_2, \ldots G_i, \ldots, G_n$.

$$\text{Max } Z_0=[G_1,G_2,\ldots,G_i,\ldots,G_n] \quad (15)$$

Step 7. Set the MCGP model. An example is as follows:

$$\text{Min } Z=\sum_{i=1}^{n}\frac{w_i}{L_i}(d_{i1}^{+}+d_{i1}^{-}+L_i(d_{i2}^{+}+d_{i2}^{-})) \quad (16)$$

$$\text{s.t. } f_i(X)-d_i^{+}+d_i^{-}=\sum_{j=1}^{m}g_{ij}S_{ij}(B),\ i=1,2,\ldots,n \quad (17)$$

$$f_i(X)-d_{i1}^{+}+d_{i1}^{-}=g_i^{max}z_i+g_i^{min}(1-z_i),\ i=1,2,\ldots,n \quad (18)$$

$$\frac{1}{L_i}(g_i^{max}z_i+g_i^{min}(1-z_i))-d_{i2}^{+}+d_{i2}^{-}=\frac{1}{L_i}(g_i^{max}\ or\ g_i^{min}),$$
$$i=1,2,\ldots,n \quad (19)$$

$$d_i^{+},d_i^{-},d_{i1}^{+},d_{i1}^{-},d_{i2}^{+},d_{i2}^{-}\geq 0,\ i=1,2,\ldots,n \quad (20)$$

$$X\in B \ (\boldsymbol{B} \text{ is a feasible set}) \quad (21)$$

$$z_i\in\{0,1\} \quad (22)$$

5. A case study for evaluating TFT-LCD companies

To examine the practicality and the effectiveness of the proposed MCGP model for supplier evaluation, we use an anonymous notebook (NB) manufacturing company in Taiwan in the selection of TFT-LCD company(s) as an example. Depending on the factor used, one TFT-LCD company may perform better than the others. Therefore, experts are interviewed first to decide the factors for selecting suppliers. The procedures and results of the proposed model in the case study are as follows.

Purchasing managers and related experts in the anonymous company are invited to define the TFT-LCD supplier selection problem and to prepare a supplier candidates list. With a comprehensive review of literature, consultation with domain experts and consideration of data accessibility, the major factors for selecting TFT-LCD companies are unit purchase cost (C), yield rate and number of suppliers. A questionnaire is prepared for the decision makers to compare factors pairwisely in their contribution toward achieving the goal of selecting the best TFT-LCD supplier. The integrated fuzzy matrix is calculated by equation (20) and is shown in Table 2. The consistency of the integrated fuzzy matrix is examined.

Five potential TFT-LCD companies in Taiwan are selected for evaluation. Because the NB company is located in Taiwan, which has many well-known and larger-scale TFT-LCD manufacturers, it is in the best interest of the NB company to simply select the suppliers in Taiwan for cooperation.

6. Conclusions

Supplier selection and evaluation process is very complicated with interrelationship among two or more organizations in a supply chain. In addition, the process is multi-objective in nature. The selection of one (or several) TFT-LCD manufacturers for subcontracting is essential for a notebook company and any other company that requires TFT-LCD modules. In this research, an MCGP model is proposed to evaluate the performance of TFT-LCD manufacturers and to allocate the purchase amount to the selected companies, while the number of suppliers that should be selected can be set as preferred. Fuzzy AHP is applied first to obtain the weights of the criteria, and an MCGP approach is used to find the optimal solution of module allocation to suppliers. We testify that the proposed model not only can consider multi-choice aspiration levels in each goal, decision making behavior and limit of resources, but it can also allocate the purchase among the selected supplier(s).

References

[1] I. McCarthy, & A. Anagnostou, The impact of outsourcing on the transaction costs and boundaries of manufacturing, *International Journal of Production Economics, 88*, 2004, 61-71.

[2] S.H. Ghodsypour, & C. O'Brien, A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming, *International Journal of Production Economics, 56-57*, 1998,199-212.

[3] F. Roodhooft, & J. Konings, Vendor selection and evaluation: an activity based costing approach, *European Journal of Operational Research, 96*(1), 1997, 97-102.

[4] G.H. Hong, S.C. Park, D.S. Jang, & H.M. Rho, An effective supplier selection method for constructing a competitive supply-relationship, *Expert Systems with Application*s, *28*, 2005, 629-639.

[5] M. Kumar, P. Vrat, & R. Shankar, A fuzzy goal programming approach for vendor selection problem in a supply chain, *Computers and Industrial Engineering, 46*, 2004, 69-85.

[6] C. Muralidharan, N. Anantharaman, & S.G. Deshmukh, A multi-criteria group decisionmaking model for supplier rating, *Journal of Supply Chain Management, 38*(4), 2002, 22-33.

[7] C.A. Weber, & A. Desai, Determination of path to vendor market efficiency using parallel coordinates representation: A negotiation tool for buyers, *European Journal of Operational Research, 90,* 1996, 142-155.

[8] C.A. Weber, J.R. Current, & A. Desai, Non-cooperative negotiation strategies for vendor selection, *European Journal of Operational Research, 108,* 1998, 208-223.

[9] C.A. Weber, & J.R. Current, A multi-objective approach to vendor selection, *European Journal of Operational Research, 68*(2), 1993, 173-184.

[10] C.A. Weber, A data envelopment analysis approach to measuring vendor performance, *Supply Chain Management, 1*(1), 1996, 28-30.

[11] K.L. Choy, W.B. Lee, & V. Lo, Design of an intelligent supplier relationship management system: a hybrid case based neural network approach, *Expert Systems with Applications, 24,* 2003, 225-237.

[12] F.-H.F. Liu, & H.L. Hai, The voting analytic hierarchy process method for selecting supplier, *International Journal of Production Economics, 97,* 2005, 308-317.

[13] C.S. Yu, A GP-AHP method for solving group decision-making fuzzy AHP problems, *Computers and Operations Research, 29*, 2002, 1969-2001.

[14] G.I. Klir, B. Yan, *Fuzzy Sets and Fuzzy Logic Theory and Applications*, London: Prentice-Hall International, 1995.

[15] R.R. Yagar, On a general class of fuzzy connective, *Fuzzy Sets and Systems*, *4*, 1978, 235-242.

[16] C.-T. Chang, Multi-choice goal programming, *Omega: The International Journal of Management Science*, *35*(4), 2007, 389-396

[17] D. Sharma, W.C. Benton, & R. Srivastava, Competitive strategy and purchasing decisions, *Proceedings of the 1989 Annual Conference of the Decision Sciences Institute*, 1989, 1088–1090.

[18] F.P. Buffa, & W.M. Jackson, A goal *programming* model for purchase planning, *Journal of Purchasing and Materials Management*, Fall, 1983, 27–34.

[19] G. Wang, S.H. Huang, & J.P. Dismukes, Product-driven supply chain selection using integrated multi-criteria decision-making methodology, *International Journal of Production Economics*, *91*, 2004, 1-15.

[20] L.-H. Chen, & F.-C. Tsai, Fuzzy goal programming with different importance and priorities, *European Journal of Operational Research, 133*, 2001, 548-556.

[21] R. Narasimhan, Goal programming in a fuzzy environment, *Decision Sciences, 11*, 1980, 243-252.

[22] J.S. Kim, & K.-S. Whang, A tolerance approach to the fuzzy goal programming problems with unbalanced triangular membership function, *European Journal of Operational Research, 107*, 1998, 614-624.

[23] A. Charnes, & W.W. Cooper, *Management Model and Industrial Application of Linear Programming*, Wiley, New York, 1961.

[24] J.J. Buckley, Fuzzy hierarchical analysis, *Fuzzy Sets and Systems, 17***,** 1985, 233-247.

[25] R. Csutora, & J.J. Buckley, Fuzzy hierarchical analysis: the Lambda-Max method, *Fuzzy Sets and Systems*, *120,* 2001, 181-195.

計畫成果自評

本計畫之相關成果已發表至 EI 級國際研討會並已投稿至 SCI 之國際期刊。

International conference:

TFT-LCD supplier selection by downstream manufacturer using fuzzy multi-choice goal programming, *The Third IASTED International Conference on Computational Intelligence*, Banff, Canada. (EI Conference)

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

96 年 7 月 9 日

附件三

報告人姓名	李欣怡	服務機構及職稱	工業工程與系統管理學系副教授
時間 會議 地點	自 96 年 7 月 2 日至 96 年 7 月 4 日 Banff, Canada	本會核定補助文號	NSC 95-2416-H-216-003
會議名稱	（中文）第三屆 IASTED 計算智慧國際研討會 （英文）The Third IASTED International Conference on Computational Intelligence		
發表論文題目	（中文）利用模糊多選擇目標規劃在下游廠商對 TFT-LCD 廠商之選擇 （英文）TFT-LCD supplier selection by downstream manufacturer using fuzzy multi-choice goal programming		

表 Y04

報告內容應包括下列各項：

一、參加會議經過

The International Conference on Computational Intelligence (CI 2007) was a major forum for international researchers and professionals to present their latest research, results, and ideas in all areas of computational intelligence. The conference proceedings are EI-indexed. The relevant topics for this conference include Ant Colony Optimization, Artificial Intelligence, Artificial Neural Systems, Chaotic and Complex Systems, Computational Intelligence, Data Fusion and Mining, Expert Systems, Fuzzy Systems, Genetic Programming, etc. The conference featured one distinguished keynote speaker: Gheorghe Tecuci (George Mason University, USA) with topic “From Personal Computers to Learning Assistants: Development and Use of Intelligent Agents by Non-Computer Scientists.” His presentation on intelligent agents was intended to be at the crossroads of computational and artificial intelligence.

二、與會心得

The scientific level of a conference is controlled by the quality of the reviews. Each paper was blind peer-reviewed by three reviewers. The CI 2007 conference had an acceptance rate of only 56%. In the conference, I presented a paper entitled “TFT-LCD supplier selection by downstream manufacturer using fuzzy multi-choice goal programming,” and the topic attracted the attention of attendants because the issue has not been researched a lot in the past. I also served as a session chair of Session 5 -“Neuro-Fuzzy Systems,” and this gave me, our university and Taiwan a great opportunity to be known by other scholars.

三、考察參觀活動(無是項活動者省略)

None.

四、建議

Even though the NSF funds us for attending conferences overseas, the funding is limited. The total expenditures incurred were much higher than the supports from the NSC. For instance, the airfare from Taipei-Vancouver-Banff-Vancouver-Taipei was very expensive, around NT$54,000. The NSC allowable amount for the destination is only NT$39,000. In order to share research findings and practical experiences with scholars in other parts of the world and to enhance our research ability, I sincerely suggest the NSC to adjust airfare quotes and daily allowances overseas to meet the real market prices and to increase the funding for teachers who are willing to present in international conferences.

五、攜回資料名稱及內容

1. Conference Program: The Third IASTED International Conference on Computational Intelligence.
2. CD of the proceedings.

六、其他

TFT-LCD SUPPLIER SELECTION BY DOWNSTREAM MANUFACTURER USING FUZZY MULTI-CHOICE GOAL PROGRAMMING

Amy Hsin-I Lee [1*] He-Yau Kang [2] Chun-Mei Lai [3] Wei-Ming Wang [4] and Chang-Fu Hsu [5]

[1] Department of Industrial Engineering and System Management, Chung Hua University
*corresponding author. Non.707, Sec. 2, WuFu Rd., Hsinchu, Taiwan
amylee@chu.edu.tw

[2] Department of Industrial Engineering and Management, National Chin-Yi University of Technology, Taiwan
kanghy@ncit.edu.tw

[3] Department of Industrial and Business Management, Far East University, Taiwan
chunmei@cc.fec.edu.tw

[4] Department of Architecture & Urban Planning, Chung Hua University, Taiwan
weiming@chu.edu.tw

[5] Quality Assurance Division, United Microelectronics Company, Taiwan
Department of Industrial Engineering and Management, National Chiao Tung University, Taiwan
abel_hsu@umc.com

ABSTRACT

A good supply chain relationship is essential for a company to survive and to acquire reasonable profit in today's highly competitive global environment. Only very few large companies can and are willing to vertically integrate from the design stage to the final distribution of the entire supply chain. Most companies focus on their specialized functions and to cooperate with upstream or downstream companies. As a result, supplier selection is important for maintaining a certain degree of strategic alliance. This paper aims to develop a fuzzy multi-choice goal programming (FMCGP) model to help downstream companies to select thin film transistor liquid crystal display (TFT-LCD) suppliers for cooperation. First, fuzzy analytic hierarchy process (FAHP) is applied to analyze the importance of multiple factors by incorporating experts' opinion. Next, multi-choice goal programming is used to consider the limits of various resources and to formulate the constraints. From the experimental design and examination, we shall testify that the proposed model not only can consider multi-choice goals, decision making behavior and limit of resources, but it can also allocate the purchase among the selected supplier(s).

KEY WORDS

Supplier selection, Performance, TFT-LCD, Multi-choice goal programming, Fuzzy analytic hierarchy process

1. Introduction

The TFT-LCD supply chain involves the domains of optics, semiconductor, electrical engineering, chemical engineering, mechanical engineering and material. Because a wide variety of technologies are required from the upstream to the downstream in the supply chain, very few companies have the capability and are willing to cover all operations from the making of material to the manufacturing of final products in the supply chain. Therefore, division of works and cooperation among companies are necessary in the TFT-LCD industry. The TFT-LCD supply chain is usually segregated into three parts: upstream, midstream and downstream. The upstream includes the equipment (e.g. photo/etch equipment) and the material and components (e.g. glass substrate, backlight module and driver IC). By using the equipment provided by equipment suppliers and the material provided by the material/components suppliers, the midstream companies first manufacture panels and then assembled them into TFT-LCD modules. Downstream manufacturers use the modules to make final products such as notebook computer, LCD monitors, etc.

Outsourcing has become an important business approach in various industries since a competitive advantage may be gained by cooperating with suppliers to provide products/services more effectively and efficiently [1]. Companies in a TFT-LCD supply chain usually focus on only one or two steps in the supply chain while outsourcing the rest of steps to other companies. For instance, a TFT-LCD manufacturing company may receive orders from a notebook manufacturing company, which specifies the specification of the panels, and manufacture TFT-LCD modules according to the design. It also needs to find upstream companies to obtain the required equipment, material and components. On the other hand, for a notebook manufacturing company, it also needs to find one or several suitable TFT-LCD manufacturing companies to obtain the required TFT-LCD module for further producing notebook computers. In consequence, the selection of the right companies for cooperation is important for maintaining a competitive edge. In addition, how to distribute the amount of purchases to the selected manufacturers is also a problem faced by the purchasing companies.

The rest of this paper is organized as follows. Section 2 reviews some recent researches on supplier selection. FAHP and goal programming are discussed in Section 3. Section 4 proposes a FMCGP model applied to select TFT-LCD companies by downstream manufacturers. Some concluding remarks are made in the last section.

2. Supplier Selection Problem

In current business environment, global competition is inevitable, and customer demands are diversified. This results in progressively increased costs and sharply decreased profit. Therefore, purchasing has become a crucial job in establishing value-added contents of products and a vital determinant to ensure the profitability and survival of a company. Many companies are trying to reduce their costs while satisfying customer needs by strengthening their core competencies and outsourcing other functions. Suppliers have varied strengths and weaknesses; thus, supplier selection requires a careful assessment in order to maintain a continuous good buyer-supplier relationship.

Categorical method is the simplest supplier selection method. Each supplier characteristic is assigned good, satisfactory, neutral and unsatisfactory and then the total score for each supplier is summed up [2]. Linear weighing method is one of the most common methods, and the concept is to give different weights to a number of criteria and to select the supplier with the best weighted total score [3]. Although most proposed methods belong to linear weighting and mathematical programming (MP) models [4], MP models are proved more effective than the linear weighting methods because they can optimize the explicitly stated objective [5]. Muralidharan *et al.* [6] did a comparison of various supplier rating methods and listed the advantages and limitations of the methods.

A MP model formulates the decision problem in terms of a mathematical objective function that needs to be maximized (e.g. profit) or minimized (e.g. cost) by varying the values of variables in the objective function (e.g. the amount ordered with a supplier) [4]. Most-used MP models in supplier selection are linear programming, mixed integer programming, and goal programming/multi-objective goal programming (MOP). Weber and Desai [7], Weber *et al.* [8] and Muralidharan *et al.* [6] reviewed past supplier selection researches by MP models. Hong *et al.* [4] proposed a mathematical programming model that considers the change in suppliers' supply capabilities and customer needs over a period in time, and the model not only can maximize revenue but also can satisfy customer needs. Multi-objective programming (MOP) is a very popular tool since many criteria, not a single criterion, can be examined with different weights. Weber and Current [9] introduced a MOP for selecting suppliers with order quantities in procurement environments characterized by multiple conflicting criteria. Weber (1996) applied DEA in supplier evaluation for an individual product and demonstrated the advantages of applying DEA.

Two or more methodologies can be combined in the evaluation of suppliers. Ghodsypour and O'Brien [2] combined AHP and linear programming to choose the best supplier and to assign the optimum order quantity among selected suppliers. Weber *et al*. [8] integrated MOP and DEA to deal with non-cooperative supplier negotiation strategies where the selection of one supplier results in another being left out of the solution. Choy *et al.* [11] designed an intelligent supplier relationship management system by using hybrid case based reasoning and artificial neural networks techniques, to select and benchmark potential suppliers. Liu and Hai [12] proposed a voting AHP method, which combined AHP and DEA, for selecting supplier by comparing the weighted sum of the selection number of rank vote, after determining the weights in a selected rank.

3. FAHP and Goal Programming

The AHP is a mathematically based MCDM tool. It is very popular to academic researchers for data analysis and model verifications and to provide critical information for decision makers in various fields such as political, social, economic and management sciences. A complex problem is decomposed into several sub-problems in terms of hierarchical levels, and the factors of the same hierarchical level are compared relative to their impact on the solution of their higher level factor. Pairwise comparisons are employed among decision elements, and comparison matrices are formed. After the consistency of the matrices is examined, the relative weights of decision elements are estimated next. The relative weights are aggregated lastly to obtain an overall rating for the decision alternatives.

Fuzziness and vagueness are common characteristics in many decision-making problems, and a good decision-making model should be able to tolerate vagueness or ambiguity [13]. In addition, decision makers very naturally provide uncertain answers rather than precise values, and it is difficult to transform qualitative preferences to point estimates. Therefore, pairwise comparison under traditional AHP may not be appropriate due to the necessity of selecting arbitrary values in the process, and a degree of uncertainty should be considered in some or all pairwise comparison values [13]. In consequence, the incorporation of the fuzzy theory in AHP should be more appropriate and effective than conventional AHP. Many researches have been done on the development and the application of FAHP, and tremendous amount of FAHP methodologies are existed.

In the last step of FAHP, the total ranking fuzzy numbers for decision elements (e.g. alternatives) are obtained, and the fuzzy numbers need to be ranked. There are many different methods to do the ranking, and each method has its own advantages and disadvantages [14]. Centroid ranking method is a popular way [15]. Let $f_c(x)$ be a membership function for triangular fuzzy number $C=(p,q,s)$, the centroid ranking method formula of triangular fuzzy number C is [15]:

$$R(C)=\int xf_C(x)dx \Big/ \int f_C(x)dx \tag{1}$$

Define $C_i=(p_i,q_i,s_i)$, $i=1,2,...,n$ be n triangular fuzzy numbers. By the formula stated above, one can obtain the centroid rank value of triangular fuzzy number:

$$R(C_i)=\left[\frac{1}{q_i-p_i}\left(\frac{1}{3}q_i^3-\frac{1}{2}q_i^2p_i+\frac{1}{6}p_i^3\right)+\frac{1}{s_i-q_i}\left(\frac{1}{3}q_i^3-\frac{1}{2}q_i^2s_i+\frac{1}{6}s_i^3\right)\right]\Big/\left[\frac{1}{2}(s_i-p_i)\right] \tag{2}$$

Finally, the centroid rank value of triangular fuzzy numbers is:

$$R(C_i)=\tfrac{1}{3}(p_i+q_i+s_i) \tag{3}$$

A goal programming (GP) model is useful in dealing with multi-criteria decision problems where the goals cannot simultaneously be optimized. GP allows decision makers to consider several objectives together in finding a set of acceptable solutions and to obtain an optimal compromise. The purpose of GP is to minimize the deviations between the achievement of goals and their aspiration levels [16]. Sharma *et al.* [17] proposed a GP formulation for vendor selection to attain goals pertaining to price, quality and lead-time under demand and budget constraints. Buffa and Jackson [18] also proposed the use of GP for price, quality and delivery objectives to evaluate vendors. An integrated AHP and preemptive goal programming based multi-criteria decision-making (MCDM) methodology is developed by Wang *et al.* [19] to select the best set of multiple suppliers to satisfy capacity constraint.

Determining precisely the goal value of each objective is difficult for decision makers since possibly only partial information can be obtained [20]. Some approaches, such as probability distribution, penalty function fuzzy numbers and various types of thresholds, are used to reformulate the GP models in order to incorporate uncertainty and imprecision into the formulation [20]. Narasimhan [21] was the first to propose fuzzy goal programming (FGP) by using the fuzzy set theory with preference-based membership function to GP. Since then, many achievements have been made in areas of preemptive FGP, weight additive model and stochastic model [16].

Kim and Whang [22] investigated the application of tolerance concepts to goal programming in a fuzzy environment by formulating a FGP problem with unequal weights as a single linear programming problem with the concept of tolerance. The model could reflect the decision maker's view on subjective fuzzy business goals based on his/her experience or intuition. Chen and Tsai [20] formulated FGP by "incorporating different importance and preemptive priorities by using an additive model to maximize the sum of achievement degrees of all fuzzy goals." The approach allowed the decision maker to determine a desirable achievement degree for each fuzzy goal and to reflect explicitly the relative importance of these goals. Kumar *et al.* [5] presented a fuzzy goal programming approach that considered multiple objectives and dealt with some of the parameters that were fuzzy in nature. A fuzzy mixed integer goal programming was formulated. Three primary goals are minimizing the net cost, minimizing the net rejections, and minimizing the net late deliveries, while the constraints are regarding buyer's demand, vendors' capacity, vendors' quota flexibility, purchase value of items, budget allocation to individual vendor, etc.

Chang [16] proposed an MCGP approach to solve a multi-choice aspiration level (MCAL) problem, in which decision makers can set more aspiration levels to each goal of the multiple objective decision-making problem to find more appropriate resources so as to reach a higher aspiration level in the initial stage of the solution process. The approach is applicable when there is a goal that can be achieved from some specific aspiration levels (i.e., one goal mapping many aspiration levels) [16].

The achievement function of MCGP is [16]:

$$\text{Min } \sum_{i=1}^{n} w_i(d_i^+ + d_i^-) \tag{4}$$

$$\text{s.t. } f_i(X) - d_i^+ + d_i^- = \sum_{j=1}^{m} g_{ij}S_{ij}(B) \quad , i=1,2,...,n \tag{5}$$

$$d_i^+, d_i^- \geq 0 \quad , i=1,2,...,n \tag{6}$$

$$S_{ij}(B) \in U_i(x), \qquad i = 1,2,...,n \qquad (7)$$

$$X \in F \ \ (F \text{ is a feasible set}) \qquad (8)$$

where d_i is the deviation from the target value g_i; w_i represents the weight attached to the deviation; $d_i^+ = max(0, f_i(X) - g_i)$ and $d_i^- = max(0, g_i - f_i(X))$ are, respectively, over- and under-achievements of the *i*th goal; $S_{ij}(B)$ represents a function of binary serial number; and $U_i(x)$ is the function of resources limitations.

For something that is more/higher the better in the aspiration levels, the highest possible value of membership function is 1, based on the fuzzy theory [23]. To achieve the maximization of $g_{ij}S_{ij}(B)$, the flexible membership function goal with aspiration level 1 (i.e., the highest possible value of membership function) is used as follows [16]:

$$\frac{g_{ij}S_{ij}(B) - g_{min}}{g_{max} - g_{min}} - d_i^+ + d_i^- = 1 \qquad (9)$$

where $g_{\max}$ and $g_{\min}$ are, respectively, the upper and lower bound of the right-hand side (i.e., aspiration levels) of equation (6).

For easy calculation, the fractional form of equation (7) is [16]:

$$\frac{1}{L_i} g_{ij}S_{ij}(B) - \frac{1}{L_i} g_{min} - d_i^+ + d_i^- = 1 \qquad (10)$$

where $L_i = g_{max} - g_{min}$.

4. Formulation of fuzzy multi-choice goal programming for TFT-LCD manufacturer selection

In this section, an MCGP model with the incorporation of FAHP is proposed for the selection of TFT-LCD manufacturers by a notebook (NB) manufacturer. The steps can be summarized as follows:

Step 1. Form a committee of experts in NB industry and define the TFT-LCD supplier selection problem. The selection of suitable TFT-LCD manufacturers for a NB company to purchase TFT-LCD modules is essential for the NB company to be successful. With a comprehensive review of literature, consultation with domain experts and consideration of data accessibility, the factors for determining the performance of TFT-LCD companies can be organized.

Step 2. Formulate a questionnaire to compare factors pairwisely in their contribution toward achieving the goal of selecting the best TFT-LCD supplier. Five-point scale is applied, and the opinions of experts are collected and combined into a fuzzy pairwise comparison matrix $\tilde{A}$.

$$\tilde{A} = [\tilde{a}_{i\rho}] = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & 1 & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix}, \text{ for } i,\rho = 1,2,\ldots n \qquad (11)$$

where $\tilde{a}_{i\rho} = (l_{i\rho}, m_{i\rho}, u_{i\rho})$ and $a_{i\rho} \cdot a_{\rho i} \approx 1$,

$l_{i\rho}$ ：the smallest assigned value among the experts,

$m_{i\rho}$ ：the largest assigned value among the experts, and

$u_{i\rho}$ ：the geometric average of the values of all other experts.

Step 3. Check the consistency of the fuzzy matrix and obtain FAHP weight, $\tilde{w}$. Based on Buckley [24] and Csutora and Buckley [25], let $\boldsymbol{A}=[a_{i\rho}]$ be a positive reciprocal matrix, and $\tilde{A} = [\tilde{a}_{i\rho}]$ be a fuzzy positive reciprocal matrix, if $\boldsymbol{A}$ is consistent, then $\tilde{A}$ is also consistent. If $\tilde{A}$ is not consistent, the questionnaire must be modified by the experts. The fuzzy weight $\tilde{w}$ is:

$$\tilde{w}_i = [\tilde{a}_{i1} \otimes \cdots \otimes \tilde{a}_{in}]^{1/n}, \text{ for } i=1,2\ldots n \qquad (12)$$

Step 4. Defuzzy $\tilde{w}$ by the centroid method. Each fuzzy number of $\tilde{w}$ is defuzzied to get a best crisp value:

$$\overline{w}_i = (w_{i1} + w_{i2} + w_{i3})/3, \text{ for } i=1,2\ldots n \qquad (13)$$

Step 5. Normalize the weights of factors. The weights of the factors are normalized by the following:

$$w_i = \overline{w}_i \Big/ \sum_{i=1}^{n} \overline{w}_i, \text{ for } i=1,2\ldots n \qquad (14)$$

Step 6. Set the GP model for the supplier selection. The objective is to maximize the satisfaction of the suppliers, and the goals are $G_1, G_2, \ldots G_i, \ldots, G_n$.

$$\text{Max } Z_0 = [G_1, G_2, ..., G_i, ..., G_n] \qquad (15)$$

Step 7. Set the MCGP model. An example is as follows:

$$\text{Min } Z = \sum_{i=1}^{n} \frac{w_i}{L_i} (d_{i1}^{+} + d_{i1}^{-} + L_i (d_{i2}^{+} + d_{i2}^{-})) \quad (16)$$

$$\text{s.t. } f_i(X) - d_i^{+} + d_i^{-} = \sum_{j=1}^{m} g_{ij} S_{ij}(B) \text{ , } i = 1,2,...,n \quad (17)$$

$$f_i(X) - d_{i1}^{+} + d_{i1}^{-} = g_i^{max} z_i + g_i^{min} (1 - z_i) \text{ , } i = 1,2,...,n \quad (18)$$

$$\frac{1}{L_i}(g_i^{max} z_i + g_i^{min} (1 - z_i)) - d_{i2}^{+} + d_{i2}^{-} = \frac{1}{L_i}(g_i^{max} \text{ or } g_i^{min}), \quad i = 1,2,...,n \quad (19)$$

$$d_i^{+}, d_i^{-}, d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-} \geq 0 \quad , i = 1,2,...,n \quad (20)$$

$$X \in B \quad (\boldsymbol{B} \text{ is a feasible set}) \quad (21)$$

$$z_i \in \{0,1\} \quad (22)$$

5. Conclusions

Supplier selection and evaluation process is very complicated with interrelationship among two or more organizations in a supply chain. In addition, the process is multi-objective in nature. The selection of one (or several) TFT-LCD manufacturers for subcontracting is essential for a notebook company and any other company that requires TFT-LCD modules. In this research, an MCGP model is proposed to evaluate the performance of TFT-LCD manufacturers and to allocate the purchase amount to the selected companies, while the number of suppliers that should be selected can be set as preferred. Fuzzy AHP is applied first to obtain the weights of the criteria, and an MCGP approach is used to find the optimal solution of module allocation to suppliers. For the future research, a case study will be carried out. We shall testify that the proposed model not only can consider multi-choice aspiration levels in each goal, decision making behavior and limit of resources, but it can also allocate the purchase among the selected supplier(s).

Acknowledgements

This research is supported in part by National Science Council, Taiwan, under Grant NSC 95-2416-H-216-003.

References

[1] I. McCarthy, & A. Anagnostou, The impact of outsourcing on the transaction costs and boundaries of manufacturing, *International Journal of Production Economics, 88*, 2004, 61-71.

[2] S.H. Ghodsypour, & C. O'Brien, A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming, *International Journal of Production Economics, 56-57*, 1998,199-212.

[3] F. Roodhooft, & J. Konings, Vendor selection and evaluation: an activity based costing approach, *European Journal of Operational Research, 96*(1), 1997, 97-102.

[4] G.H. Hong, S.C. Park, D.S. Jang, & H.M. Rho, An effective supplier selection method for constructing a competitive supply-relationship, *Expert Systems with Application*s, *28*, 2005, 629-639.

[5] M. Kumar, P. Vrat, & R. Shankar, A fuzzy goal programming approach for vendor selection problem in a supply chain, *Computers and Industrial Engineering*, *46*, 2004, 69-85.

[6] C. Muralidharan, N. Anantharaman, & S.G. Deshmukh, A multi-criteria group decisionmaking model for supplier rating, *Journal of Supply Chain Management, 38*(4), 2002, 22-33.

[7] C.A. Weber, & A. Desai, Determination of path to vendor market efficiency using parallel coordinates representation: A negotiation tool for buyers, *European Journal of Operational Research, 90,* 1996, 142-155.

[8] C.A. Weber, J.R. Current, & A. Desai, Non-cooperative negotiation strategies for vendor selection, *European Journal of Operational Research, 108*, 1998, 208-223.

[9] C.A. Weber, & J.R. Current, A multi-objective approach to vendor selection, *European Journal of Operational Research, 68*(2), 1993, 173-184.

[10] C.A. Weber, A data envelopment analysis approach to measuring vendor performance, *Supply Chain Management, 1*(1), 1996, 28-30.

[11] K.L. Choy, W.B. Lee, & V. Lo, Design of an intelligent supplier relationship management system: a hybrid case based neural network approach, *Expert Systems with Applications, 24,* 2003, 225-237.

[12] F.-H.F. Liu, & H.L. Hai, The voting analytic hierarchy process method for selecting supplier, *International Journal of Production Economics, 97,* 2005, 308-317.

[13] C.S. Yu, A GP-AHP method for solving group decision-making fuzzy AHP problems, *Computers and Operations Research, 29*, 2002, 1969-2001.

[14] G.I. Klir, B. Yan, *Fuzzy Sets and Fuzzy Logic Theory and Applications*, London: Prentice-Hall International, 1995.

[15] R.R. Yagar, On a general class of fuzzy connective, *Fuzzy Sets and Systems, 4*, 1978, 235-242.

[16] C.-T. Chang, Multi-choice goal programming, *Omega: The International Journal of Management Science, 35*(4), 2007, 389-396

[17] D. Sharma, W.C. Benton, & R. Srivastava, Competitive strategy and purchasing decisions, *Proceedings of the 1989 Annual Conference of the Decision Sciences Institute*, 1989, 1088–1090.

[18] F.P. Buffa, & W.M. Jackson, A goal *programming* model for purchase planning, *Journal of Purchasing and Materials Management*, Fall, 1983, 27–34.

[19] G. Wang, S.H. Huang, & J.P. Dismukes, Product-driven supply chain selection using integrated multi-criteria decision-making methodology, *International Journal of Production Economics, 91*, 2004, 1-15.

[20] L.-H. Chen, & F.-C. Tsai, Fuzzy goal programming with different importance and priorities, *European Journal of Operational Research*, *133*, 2001, 548-556.

[21] R. Narasimhan, Goal programming in a fuzzy environment, *Decision Sciences, 11*, 1980, 243-252.

[22] J.S. Kim, & K.-S. Whang, A tolerance approach to the fuzzy goal programming problems with unbalanced triangular membership function, *European Journal of Operational Research, 107,* 1998, 614-624.

[23] A. Charnes, & W.W. Cooper, *Management Model and Industrial Application of Linear Programming*, Wiley, New York, 1961.

[24] J.J. Buckley, Fuzzy hierarchical analysis, *Fuzzy Sets and Systems*, *17***,** 1985, 233-247.

[25] R. Csutora, & J.J. Buckley, Fuzzy hierarchical analysis: the Lambda-Max method, *Fuzzy Sets and Systems*, *120*, 2001, 181-195.