Order Partitioning in Hybrid MTS/MTO Contexts using Fuzzy ANP

H. Rafiei, M. Rabbani

***Abstract*—**A novel concept to balance and tradeoff between make-to-stock and make-to-order has been hybrid MTS/MTO production context. One of the most important decisions involved in the hybrid MTS/MTO environment is determining whether a product is manufactured to stock, to order, or hybrid MTS/MTO strategy. In this paper, a model based on analytic network process is developed to tackle the addressed decision. Since the regarded decision deals with the uncertainty and ambiguity of data as well as experts' and managers' linguistic judgments, the proposed model is equipped with fuzzy sets theory. An important attribute of the model is its generality due to diverse decision factors which are elicited from the literature and developed by the authors. Finally, the model is validated by applying to a real case study to reveal how the proposed model can actually be implemented.

***Keywords*—**Fuzzy analytic network process, Hybrid make-to-stock/make-to-order, Order partitioning, Production planning.

I. Introduction

SINCE diverse activities are involved in manufacturing context, it is crucial to develop a manufacturing structure to deal with the associated complex atmosphere. An approach toward handling this complex framework has been Hierarchical Production Planning (HPP) which was firstly introduced by Hax and Meal [1] in the mid-1970s. HPP divides manufacturing structure into several levels each of which deals with different category of issues. In this approach, decision associated with each level is made sequentially and the results obtained from each level enter the next level as parameter, constraint, or some decision factors and criteria. Generally, the attribute used to distinguish these levels is time horizon involved in each level; i.e. time horizons are shorter as decision moves downward in the HPP. From standpoint of activities, each level of hierarchy associates with distinct decision nature, ranged from strategic to operational.

A. MTS, MTO and hybrid MTS/MTO

Ever growing competitive markets have emerged embedding new requirements to the delivered products, such as customization and production flexibility. This approach makes another perspective involved in manufacturing environment, leading to a question: How much do customer orders influence production strategy and style? Regarding different stages in production flow line, diverse production strategies can be obtained with respect to the point in the value chain in which customer orders enter and from which products are manufactured according to the received orders. These strategies include Engineer-To-Order (ETO), Make-To-Order (MTO), Assemble-To-Order (ATO) and Make-To-Stock (MTS).

MTS production strategy is based on forecasts of product demands and production is triggered not taking into account customer orders. Hence, considerable holding costs or stock-out costs are inevitable in highly-fluctuating-demand contexts. Furthermore, no customization can be performed on MTS-based products, as orders occur while goods are fully processed and stocked [2]. The issues and measures involved in MTS environment are usually higher full rate, demand forecasting, lot sizing, average inventory levels, etc. [3]. Since former production systems were mostly MTS-based, a dense literature had been devoted to this production strategy. Notable instances can be [4]-[6].

In contrary to MTS, MTO is fully structured with respect to customer orders. In an MTO environment, manufacturing of a specific product is not initiated, unless a specific order is released from a customer [7]. Important issues involved in MTO systems are average response time, average order delay, shorter delivery lead time, due date setting, etc. [3]. Some researches discussing MTO manufacturing are [8]-[12].

Hybrid MTS/MTO production context is benefited from both MTS and MTO. In hybrid systems, there are two distinct stages in a shared production facility for each product; common and differentiation stages. During common stage, all products are processed through the same work centers with the same job descriptions and semi-finished products are completed in differentiation stage with respect to customer orders and associated customizations. The two above mentioned stages are separated by a stocking point corresponding to each product. Compared with MTS, hybrid MTS/MTO environments yield higher level of customization, less WIP inventories, less backlog or loss-sales costs, less holding cost, higher flexibility etc., while some characteristics, like under load utilization and greater lead times are embedded to this production strategy. To tradeoff between MTS and MTO as two extreme production systems, hybrid MTS/MTO systems have attracted practitioners and academicians to adopt this hybrid choice in recent years.

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Although this approach is one of the best fitted with many manufacturing environments, there are handful research papers dealing with hybrid MTS/MTO production strategy. Applying concept of HPP in hybrid MTS/MTO, different levels of decision must be taken into consideration with respect to both MTS and MTO products. The first level involves determining whether a product is manufactured to stock, to order, or partially to stock and to be completed upon the coming orders following hybrid MTS/MTO strategy. One of the primary researches devoted to partitioning in food processing industry is the one in [13] which regarded this issue by introducing two categories of factors; product and market characteristics, and process and stock characteristics as well as evaluation of the factors on shifting the influencing point of orders forward and backward in the production value chain. A more comprehensive research is proposed in this field by Olhager [7] who regards market, product, and production-related criteria upon which partitioning decision is made. Moreover, it is discussed what the benefits and drawbacks of shifting the point backward and forward are. Another attempt in the context of food processing industries is developed by Soman et al. [3]. The authors regard plant, production and market, and product factors from literature toward determining which products to be manufactured to stock and which ones to be manufactured to order. Their respected system is measured through capacity utilization and order-oriented performance measures for MTO products and product-oriented measures for MTS items.

However, two other models proposed in [14] and [15] are very generic and applicable to various manufacturing systems and conditions. In [14], authors proposed a model with criteria selected by experts' points of view to determine whether a product is manufactured as an MTS, MTO, or hybrid MTS/ MTO with respect to available capacity of the firm. By means of the proposed model, the authors rank products with respect to decision matrix formed by the weights of each product regarding each decision criterion [14]. Then, weights of criteria are elicited applying fuzzy Analytic Hierarchy Process (AHP) method. Fuzzy AHP is followed by TOPSIS to calculate aggregated weights of products. The decreasingly ranked orders are decided to be processed MTO, hybrid MTS/MTO and MTS, respectively; while capacity of each production category is checked before assignment of each product to above categories. The drawback of their model is capacity consideration before order partitioning, while it is usually performed after partitioning.

However, Reference [15] proposes a fuzzy AHP-SWOT methodology in which sixteen criteria were gathered as factors toward partitioning. In their model, criteria are categorized as four classes, namely Strength, Weaknesses, Opportunities, and Threats (SWOT), of which two first classes reflect internal status of firm, while two other classes cover external and environmental affecting factors. Next, a decision hierarchy comprises three levels is applied. The second and the third levels of the hierarchy represent SWOT classes and their downstream sub-criteria, respectively; while the objective level of the hierarchy addresses implementation of MTO strategy. MTO strategy is placed in the first level, because they categorized factors in SWOT classes with respect to MTO implementation. Moreover, their Multi-Attribute Decision Making (MADM) process is equipped with fuzzy sets theory [16] to tackle ambiguity and uncertainty corresponding to input data. First drawback of their proposed model is independency assumption of each factor relative to other factors. Some dependencies amongst the regarded factors must be taken into account to be able to model real instances as exactly as possible. The dependencies cannot be modeled using AHP, as this methodology assume criteria and sub-criteria independent at each level of hierarchy. Furthermore, there are some neglected factors among the ones defined by the authors. In this paper, it is challenged to compensate the drawbacks of the model proposed in [15]. To conquer dependencies, Analytic Network Process (ANP) [17] is adopted with a modified network relative to the hierarchy of AHP [18]. Additionally, authors complete the factors resulting more thorough model which can reflect real problems best. To tackle vagueness and ambiguity of experts' judgments, the proposed structure is augmented with fuzzy sets theory. Hence, a decision structure is developed in this paper to tackle order partitioning in hybrid MTS/MTO environment as well as compensating drawbacks of the previously proposed models. The remainder is organized as followings. Proposed model is elaborately described in Section 2, while validation of the proposed model is performed throughout Section 3. Finally, Section 4 comprises some concluding remarks and future research directions.

TABLE I
PARTITIONING FACTORS IN FOUR CLUSTERS (SYMBOLS IN PARENTHESES)

Category	Factor	Category	Factor
Product-related	Cost of holding(Pd1)	Market-related	Risk of obsolescence(M1)
	Product perishability(Pd2)		Demand predictability(M2)
	Modular design(Pd3)		Delivery lead-time(M3)
	Customization opportunities(Pd4)		Delivery reliability(M4)
	Product structure(Pd5)		Demand volatility(M5)
	Backorder cost(Pd6)		Product customization(M6)
Process-related	Production controllability(Pc1)		Order frequency(M7)
	Manufacturing lead-time(Pc2)		Order size(M8)
	Cost of investment(Pc3)	Supplier-related	Supplier flexibility(S1)
	Production setups(Pc4)		Supplier lead-time(S2)
	Human resource flexibility(Pc5)		
	Manufacturing flexibility(Pc6)		

II. PROPOSED MODEL

To decide on which products to be manufactured upon

MTS, which upon MTO, and which upon hybrid strategy, a model consisting of 6 major steps are developed. Fig. 1 demonstrates outline of the proposed model whose steps are described in the following sub-sections elaborately.

A. Factors toward order partitioning

Order partitioning is a strategic decision in manufacturing context which involves distinct aspects of firms. Developing more comprehensive decision structure in this paper, some factors are regarded among which some are mentioned in the literature and others are introduced herein. Developed factors are categorized in four groups; all are presented in Table I.

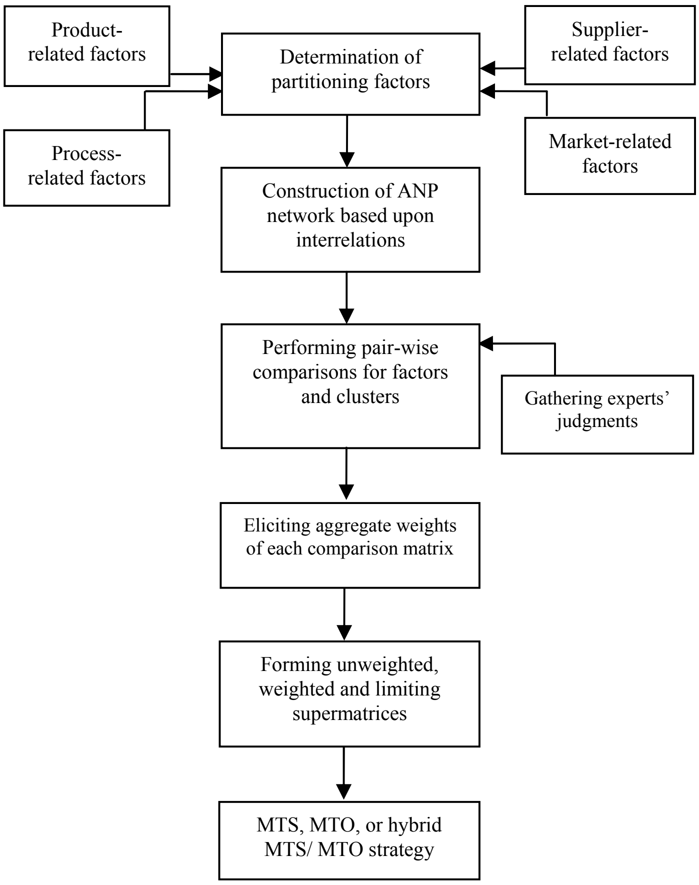

Fig. 1 Proposed order partitioning model in hybrid MTS/MTO

TABLE II
DEPENDENCY RELATIONSHIPS BETWEEN FACTORS

Ind. factor	Dep. factor	Ind. factor	Dep. factor	Ind. factor	Dep. factor	Ind. factor	Dep. factor
Pd3	Pd4	Pd5	Pd3	Pc6	Pc3	M7	M8
	Pc2		Pd4	M1	M2	M8	M7
	Pc6		Pc2	M3	M4	M6	M2
Pd4	M6	Pc2	M6	S1	Pd4		M8
Pc4	Pc3	Pc5	Pc2	S2	M4		
	Pc6		Pc6				

B. Decision network construction

With respect to the factors, dependency relations can be defined. Table II presents the relationships; i.e. dependent factors (*Dep. factor*) are influenced by the corresponding independent factor (*Ind. factor*). In addition to the relationships in Table II, it must be noted that all alternatives are dependent to elements of the decision. The ANP model is based upon these relationships.

C. Pair-wise comparisons

In this sub-section, two kinds of pair-wise comparisons are addressed. The first one is related to comparisons among elements of one cluster dependent to another element, while cluster comparisons are the second kind encompasses relative importance of clusters dependent to one cluster.

Since comparisons are linguistic, it is valuable to utilize fuzzy sets theory to tackle the uncertainty embedded in the decision in the form of triangular membership fuzzy judgments [19]. A general form of comparison matrices is shown in Fig. 2, consisting of fuzzy values. In Fig. 2, CM_l^k is the comparison matrix of elements of cluster l dependent to elements of cluster k, in which cm_{ij} is the weight of element i from cluster l relative to influencing element j from cluster k. cm_{ij} consist of three values corresponding lower, central and upper values of triangular fuzzy membership function. Additionally, a method to aggregate opinions from several experts (decision making group) must be regarded to convert different judgmental values to one element in the comparison matrix. This can be performed using arithmetic or geometric mean of N values assigned to one comparison. Equations (1) and (2) demonstrate calculation of arithmetic and geometric means, respectively [20].

$$CM_l^k = \begin{bmatrix} \left(a_{11}^l, a_{11}^c, a_{11}^u\right) & \vdots & \left(a_{1m}^l, a_{1m}^c, a_{1m}^u\right) \\ \cdots & cm_{ij} & \cdots \\ \left(a_{m1}^l, a_{m1}^c, a_{m1}^u\right) & \vdots & \left(a_{mm}^l, a_{mm}^c, a_{mm}^u\right) \end{bmatrix}$$

Fig. 2 A general fuzzy comparison matrix with triangular elements

$$\tilde{cm}_{ij} = \left(\tilde{cm}_{ij}^1 \oplus \tilde{cm}_{ij}^2 \oplus \cdots \oplus \tilde{cm}_{ij}^N\right) \Big/ N \qquad (1)$$

$$\tilde{cm}_{ij} = \left(\prod_{n=1}^{N} \tilde{cm}_{ij}^n\right)^{1/N} \qquad (2)$$

In which two following fuzzy operators are used as described below [20].

$$\tilde{A} \oplus \tilde{B} = \left(A_1 + B_1, A_2 + B_2, A_3 + B_3\right) \qquad (3)$$

$$\tilde{A} \otimes \tilde{B} = \left(A_1 B_1, A_2 B_2, A_3 B_3\right) \qquad (4)$$

where $\tilde{A}$ and $\tilde{B}$ are two fuzzy triangular numbers, also $\oplus$ and $\otimes$ are addition and multiplication operators.

Afterward, elements of matrix CM_l^k must be defuzzified in order to initiate the ANP model using the crisp values. To defuzzify the matrix, α-cut method with β level of satisfaction is applied. Using α-cut method, the interval indicating fuzzy number $\left(a_{ij}^{l}, a_{ij}^{c}, a_{ij}^{u}\right)$, is reduced to $\left(a_{\alpha ij}^{l}, a_{\alpha ij}^{u}\right)$ which is a crisp interval whose members' membership values equal or are greater than *α*. To convert elements of the resulted reduced matrix to unique crisp values, *β* level of satisfaction is applied using (5), leading to formation of matrix $CM_{\alpha l}^{\beta k}$.

$$a_{\alpha ij}^{\beta} = (1-\beta)a_{\alpha ij}^{l} + \beta a_{\alpha ij}^{u} \tag{5}$$

$$CM_{\alpha l}^{\beta k} = \begin{bmatrix} a_{\alpha 11}^{\beta} & \cdots & a_{\alpha 1m}^{\beta} \\ \vdots & \ddots & \vdots \\ a_{\alpha m1}^{\beta} & \cdots & a_{\alpha mm}^{\beta} \end{bmatrix} \tag{6}$$

D. Eliciting weights from comparison matrices

Having the comparison matrix obtained, aggregate weights of the elements must be calculated from the comparison matrix to judge about relative preferences of the elements. There are some methods to compute the aggregate weights, such as entropy, least square, eigenvector, and approximation methods [21]. In this paper, eigenvector method is adopted to perform this step as described in the followings. Supposing (7), *A*, *W* and *λ* are a specific matrix, eigenvector and eigenvalue of matrix *A*, respectively. To solve (7), (8) must hold, resulting at least one *λ*. Hence, eigenvalue of matrix *A* is the maximum value of *λ* obtained (please refer to (9)).

$$A \times W = \lambda \times W \tag{7}$$

$$|A - \lambda I| = 0 \tag{8}$$

$$\lambda_{eigen} = \max_{i} \{\lambda_i : |A - \lambda I| = 0\} \tag{9}$$

Solving (7) with λ_{eigen}, *W* is obtained as the normal relative weights of comparison elements.

E. Forming unweighted, weighted and limiting supermatrices

Eigenvectors of all possible $CM_{\alpha l}^{\beta k}$ corresponding to all clusters dependent to different elements of cluster *k* form the unweighted supermatrix of ANP model. Thereafter, elements of weighted supermatrix is computed by (10) where $ws_{\alpha lij}^{\beta k}$ and $wum_{\alpha lij}^{\beta k}$ are related to elements *i* from cluster *l* dependent to element *j* from cluster *k* of weighted supermatrix and unweighted supermatrix and $ccm_{\alpha l}^{\beta k}$ is the element of cluster comparison related to cluster *l* dependent to cluster *k*, regarding *α*-cut and *β* level of satisfaction, respectively. The resulted weighted supermatrix must be powered until its row values converge to unique value for each row.

$$ws_{\alpha lij}^{\beta k} = ccm_{\alpha l}^{\beta k} \times uws_{\alpha lij}^{\beta k} \tag{10}$$

F. MTS, MTO, or hybrid MTS/MTO

Running the proposed model through aforementioned steps, every product family holds final scores regarding three alternatives; MTS, MTO, or hybrid MTS/MTO, based upon which it is decided that product family is to be made to stock, to order, or follows a hybrid strategy, respectively.

III. Case Study

The company, called Company X hence after, has agreed to adopt the model. Company X is a home appliances manufacturer in Iran since its foundation in 1968. This company is one of the leading manufacturers in Iran, as its products have a considerable share of domestic market. Furthermore, Company X started to export some of products to several Middle Eastern, eastern European, CIS region and African countries in 1998. Unfortunately, a decreasing trend has appeared in sales volume of the company during recent three years, resulted in taking some marketing actions, such as more intensive promotion rather than past one. No improvement has been obtained through the actions emerged management to have broader market survey. The survey and corresponding managerial meetings including managers of marketing, sales, after-sales-services, R&D, engineering, procurement departments, who are the members of board, and the CEO recognized manufacturing processes as the main problem in delivering products. To overcome the issue, the proposed model has been adopted to partition firm's five kinds of products.

Based upon the factors addressed and introduced in the proposed model, decision factors are defined with respect to the type of industry in the case. As home appliances are not degraded during periods of time, product perishability is not applicable to the current case. Therefore, the case is performed with respect to the remaining of the factors. The model is run for every kind of product. Having the factors defined, cluster and element comparisons are performed upon a decision making group of managers from marketing, sales, after-sales-services, R&D, engineering, procurement departments and the CEO. The judgments of group's members are aggregated through the geometric mean of individual members' judgments. The resulted comparison matrix, denoted as CM_l^k, is entered to the model as the comparison matrix of dependent factors of cluster *l* to independent factors of cluster *k*. For instance, the aggregated board's judgment about factors of cluster *Process* dependent to factor *Pd3* for product family of *Washing machine* is the fuzzy number *(1.3459,2.6918,4.7591)*, calculated using (11), which is defuzzified by *α=0.2* and *β=0.8* to value of *3.79953*.

$$[(1,2,4) \times (2,4,6) \times (2,4,6) \times (1,2,4) \times (2,4,6) \times (1,2,4) \times (1,2,4)]^{1/7} \tag{11}$$

Having other judgments performed, supermatrices for every kind of products in the case study are structured. With respect to the limiting supermatrices of each kind, their final weights are obtained as demonstrated in Table III. Based upon the weights of each kind of products with respect to different production strategies in Table III, decided production strategies are presented in the last row of Table III.

TABLE III
FINAL DECISIONS AND ALTERNATIVES' WEIGHTS
REGARDING PRODUCT FAMILIES

Product family	Washing machine	Dishwashing machine	Refrigerator	Air conditioner	Heater
MTS/ MTO	0.03382	0.04763	0.18657	0.09826	0.16248
MTO	0.01278	0.14376	0.06734	0.15467	0.05691
MTS	0.13953	0.02370	0.05845	0.03347	0.06124
Production strategy	MTS	MTO	MTS/ MTO	MTO	MTS/ MTO

IV. CONCLUSION AND FUTURE RESEARCH DIRECTION

As the customers' requirements are the core in today competitive markets, any attempts toward obtaining customers' satisfaction play a key role in manufacturing context. Regarding the fact, hybrid MTS/MTO has been adopted in order to benefit from both MTS and MTO production strategies. The current paper is aimed to tackle the first level of hierarchical production planning approach in the hybrid MTS/MTO context, concentrating on order partitioning. The proposed model is constructed upon ANP technique which is enhanced with fuzzy sets theory to overcome the ambiguity and uncertainty of data in this level of decision. To develop a comprehensive model, decision factors of the proposed model comprise two classes of factors; the factors mentioned in the literature, and the ones introduced by the authors. Finally, a real case study was reported to describe how the model can put in practice.

Additionally, working on the proposed model can be helpful to make it more comprehensive by respecting other possible decision factors in different manufacturing contexts or to modify the model structure. Second, the current paper can be completed by spreading the concept of hybrid MTS/MTO through other levels of hierarchical production planning with their associated natures and criteria. Also, hybridization of the proposed model with some quantitative factors from operational level can builds up a mathematical model toward tactical issues, positioned between strategic and operational concerns.

REFERENCES

[1] A. C. Hax, and H. C. Meal, "Hierarchical integration of production planning and scheduling," MIT working paper, 1973.
[2] Y. Mu, Design of hybrid Make-to-Stock (MTS) - Make-to-Order (MTO) manufacturing system. M.Sc. Thesis, The University of Minnesota, 2001.
[3] C. A. Soman, D. P. van Donk, and G. Gaalman, "Combined make-to-order and make-to-stock in food production system," *Int. J. Prod. Econ.,* Vol. 90, no. 2, pp. 223-235, 2004.
[4] S. Ray, Y. Gerchak, and E. M. Jewkes, "Joint pricing and inventory policies for make-to-stock products with deterministic price-sensitive demand," *Int. J. Prod. Econ.*, vol. 97, pp. 143-158, 2005.
[5] Z. Jemaï, and F. Karaesman, "The influence of demand variability on the performance of a make-to-stock queue," *Eur. J. Oper. Res.*, vol. 164, pp. 195-205, 2005.
[6] R. Tavakkoli-Moghaddam, M. Rabbani, A. H. Gharegozli, and N. Zaerour, "A fuzzy aggregate production planning model for make-to-stock environment," *In: Proc. 2007 IEEE IEEM*, pp. 1609-1613, 2007.
[7] J. Olhager, "Strategic positioning of order penetration point," *Int. J. Prod. Econ.,* Vol. 85, pp. 319-329, 2003.
[8] S.-D. Lee, and S.-H. Ho, "Buffer sizing in manufacturing production systems with complex routings," *Int. J. Compt. Integr. Manuf.*, vol. 15, no. 5, pp. 440-452, 2002.
[9] Q.-M. He, E. M. Jewkes, and J. Buzacott, "Optimal and near-optimal inventory control policies for a make-to-order inventory-production system," *Eur. J. Oper. Res.*, vol. 141, pp. 113-132, 2002.
[10] C. Thierry, J. Lamothes, and V. Galvagnon, "Re-planning support system for make-to-order production with reserved resources," *Int. J. Prod. Res.*, vol. 42, no. 23, pp. 4993-5008, 2004.
[11] S. A. Slotnick, and M. J. Sobel, "Manufacturing lead-time rules: Customer retention versus tardiness costs," *Eur. J. Oper. Res.*, Article in press, 2004.
[12] A. Cakravastia, and K. Takahashi, "Integrated model for supplier selection and negotiation in a make-to-oeder environment," *Int. J. Prod. Res.*, vol. 42, no. 21, pp. 4457-4474, 2004.
[13] D. P. van Donk, "Make to stock or make to order: the decoupling point in the food processing industries," *Int. J. Prod. Econ.,* vol. 96, no. 3, pp. 297-306, 2001.
[14] N. Zaerpour, M. Rabbani, A. H. Gharegozli, and R. Tavakkoli-Moghaddam, "A comprehensive decision making structure for partitioning of make-to-order, make-to-stock and hybrid products," *Soft. Comput.*, 2008, DOI 10.1007/s00500-008-0377-x
[15] N. Zaerpour, M. Rabbani, A. H. Gharehgozli, and R. Tavakkoli-Moghaddam, "Make to order or make to stock decision by a novel hybrid approach," *Adv. Eng. Inform.,* vol. 22, no. 2, pp. 186-201, 2008.
[16] L. A. Zadeh, "Fuzzy sets," *Inf. Control.,* Vol. 8, pp. 338-353, 1965.
[17] T. L. Saaty, *Decision making with dependence and feedbacks: The analytic network process*, RWS Publications, 1996.
[18] T. L. Saaty, *The Analytic Hierarchical Process,* McGraw-Hill, New York, 1980.
[19] D. Y. Chang, "Applications of the extent analysis method on fuzzy AHP," *Eur. J. Oper. Res.*, vol. 95, pp. 649-655, 1996.
[20] Y.-J. Lai, and C. L. Hwang, *Fuzzy Mathematical Programming: Methods and Applications,* Springer-Verlag, New York, 1995.
[21] Mikhailov, L., Singh, M.G.: Comparison analysis of methods for driving priorities in the analytic hierarchy process. *IEEE Trans. Syst. Man. Cybern. IEEE SMC' 99*, vol. 1, pp. 1037-1042, 1999.