International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:10, 2009

An MADM Framework toward Hierarchical Production Planning in Hybrid MTS/MTO Environments

H. Rafiei, M. Rabbani

***Abstract*—**This paper proposes a new decision making structure to determine the appropriate product delivery strategy for different products in a manufacturing system among make-to-stock, make-to-order, and hybrid strategy. Given product delivery strategies for all products in the manufacturing system, the position of the Order Penetrating Point (OPP) can be located regarding the delivery strategies among which location of OPP in hybrid strategy is a cumbersome task. In this regard, we employ analytic network process, because there are varieties of interrelated driving factors involved in choosing the right location. Moreover, the proposed structure is augmented with fuzzy sets theory in order to cope with the uncertainty of judgments. Finally, applicability of the proposed structure is proven in practice through a real industrial case company. The numerical results demonstrate the efficiency of the proposed decision making structure in order partitioning and OPP location.

***Keywords*—**Hybrid make-to-stock/make-to-order, Multi-attribute decision making, Order partitioning, Order penetration point.

I. INTRODUCTION

IN the face of global competition, a manufacturing firm's survival increasingly depends on how best it can design, manage and restructure its production system to deal with product diversity, improve delivery reliability and also reduce system costs [1]. To cope with these issues, manufacturing companies often use different production systems. These production systems can be classified into two major categories: Make-To-Stock (MTS) and Make-To-Order (MTO) based on market demands' response policy [2]. The main advantage of MTS system is the short delivery time, since the final products are already in stock even before the customer order enters [1]. In an MTO system, an order is fulfilled only when it enters the system. This kind of production systems supplies a wide variety of products, usually in small quantities. Hence, ability to manufacture diverse orders and high production flexibility are the major advantages of this production system [2].

Recent years have shown a number of changes in companies' production policy and they are gradually moving toward hybrid MTS/MTO production. In MTS/MTO system, a portion of the system operates upon MTS and the remaining operates in an MTO mode [1]. A proper combination of MTO and MTS can exploit the advantages of both lower inventory and short delivery time. In such systems, some semi-finished products are maintained at one stocking point, so the production delay is just the time needed for the MTO stage to be accomplished. In the related literature, this stocking point is called Order Penetration Point (OPP) or Customer Order Decoupling Point (CODP) in the production line. Generally speaking, OPP is a point in the manufacturing value chain for a product, where the product is linked to a specific customer order and also divides the manufacturing stages that are forecast-driven from those customer-order-driven ones [3].

As discussed in [4], since MTS/MTO is a combination of two production systems, a variety of issues than those required in a pure MTS or a pure MTO system are arising in a hybrid production situation, difficult to handle simultaneously. In this regard, a hierarchical decision-making is a reasonable approach. The pioneer of the application of Hierarchical Production Planning (HPP) in hybrid MTS/MTO system is due to Soman et al. [4]. They proposed HPP with three decision making levels. These levels are MTS/MTO decision, capacity co-ordination and scheduling and control without any decision making models to specify the outputs.

In this paper, we focus on the first level of the proposed HPP framework by Soman et al. [4], which deals with determination of the appropriate product delivery strategy for different products in a manufacturing system (MTS/MTO partitioning). Moreover, we attempt to locate the position of the OPP for all products with respect to their determined delivery strategies. To make the two above strategic decisions in MTS/MTO systems, we propose a new comprehensive decision making structure. The proposed structure results in three delivery strategies: MTS, MTO and hybrid MTS/MTO. Additionally, for properly locating the OPP, we apply Analytic Network Process (ANP) [5] as a suitable multi-criteria decision making tool which considers both qualitative and quantitative criteria affecting the problem. The proposed ANP structure is enhanced with the fuzzy sets theory [6] to tackle the vagueness and ambiguity of experts' judgments.

The rest of the paper is organized as follows. The relevant

H. Rafiei is an MSc student at Department of Industrial Engineering, College of Engineering , University of Tehran, Tehran, Iran

M. Rabbani is an Associate Professor at Department of Industrial Eng., College of Engineering , University of Tehran, Tehran, Iran, P.O. Box 11155-4563 (Corresponding author: mrabani@ut.ac.ir, phone: +9821-88021067, fax: +9821-88013102).

literature is presented in Section 2. In Section 3, the proposed decision-making structure applying for MTS/MTO partitioning and OPP location is illustrated in details. To show the applicability of the proposed structure, a real industrial case study is presented in Section 4. Finally, the concluding remarks and some future research directions are provided in Section 5.

II. Literature Review

The hierarchical production planning (HPP) approach is one of the most applied methodologies for MTS companies because of its several advantages in practice (e.g. see [7]). In contrary to MTS systems, the production system in MTO firms activates only when a new order enters the system. Hence, the production planning and scheduling issues are different from those of MTS. The MTO main objective is to manage the delivery dates of arriving orders in order to reach short and reliable delivery dates. To achieve this goal, firms should apply appropriate production planning [8].

The literature review on MTS/MTO systems reveals that there are only a handful of researches regarding production planning and control in these systems. To the best of our knowledge, the thorough work in this regard carried out by Soman et al. [4]. They proposed a comprehensive HPP framework that covers the important production management decisions for MTS/MTO situations in food processing. This framework consists of a three-level decision making structure. At the first level, the decisions are taken relating to determining which products to be manufactured to order and which products to stock. At the second level, the demand and the capacity are balanced. The relevant decision at this level is allocation of production orders for both MTS and MTO products to planning periods. At the third level, there are scheduling and control decisions in which the production orders are sequenced and scheduled. Chang et al. [9] developed a heuristic production activity control model to schedule and control wafer manufacturing in a hybrid wafer production environment (hybrid MTS/MTO), while Mu [1] developed a mathematical model as a decision tool to design hybrid MTS/MTO systems and sought the economical base stock level and location necessary to meet specified service constraint. Also, he showed how to determine the optimal point separating the MTS and MTO operations for both balanced and unbalanced flow lines. Rajagopalan [10] proposed a non-linear integer program with service level constraints for MTS/MTO partitioning problem. He developed a heuristic procedure to solve this problem. Additionally, Zaerpour et al. [11] presented a novel hybrid methodology in MTS/MTO manufacturing systems for order partitioning as the most recent work. They proposed fuzzy AHP-SWOT approach as a strategic decision making methodology for product partitioning.

One of the most important issues in MTS/MTO system is the location of OPP as a strategic decision. Olhager [3] presented several factors that affect the position of the OPP and discussed the strategic rationale of shifting OPP backwards and forwards. van Donk [12] developed a framework for a decision manager in food processing industries in which he adopted the general decoupling point (DP) concept to support such decisions. After identification of influencing factors on DP, the effects of each factor are discussed on the decoupling point for a certain product/market combination. Winker and Rudberg [13] developed a conceptual framework for CODP by considering both production and engineering aspects.

As a conclusion from the previous research regarding MTS/MTO systems, there is not a decision making framework in which both MTS/MTO partitioning and OPP location decisions are made comprehensively. Also, there is a lack of holistic model to determine the exact location of OPP for the existing products manufactured in the company. To tackle the two above drawbacks in the MTS/MTO literature, a comprehensive decision making structure is proposed to choose right delivery strategy for products in MTS/MTO manufacturing systems and also, to find the appropriate location of OPP in hybrid MTS/MTO production system using fuzzy ANP.

III. Proposed Model

In this section, a comprehensive decision structure is proposed to tackle order partitioning as well as OPP location in the hybrid MTS/MTO context. In MTS/MTO environment, the adopted production strategy benefits from the strengths of both pure MTS and pure MTO strategies by processing some operations on a forecast-driven basis and finishing the products with respect to the received orders. Fig. 1 demonstrates the proposed structure which is elaborated as follows.

A. Listing all possible products

As the first step, the scope of the firm's production structure is defined. To do so, all products to be manufactured in the firm are listed. The list comprises current products and the products are planned to be produced in future. It is highly recommended that experts from engineering, marketing, R&D, manufacturing and procurement departments attend to decide what products are included in the list.

B. Pure MTS or pure MTO for listed products

Having all products listed, it is assessed whether a pure production strategy can be adopted. To decide if pure MTS or pure MTO strategy is applicable, three criteria are selected; demand volatility, P/D ratio (production lead-time to delivery lead-time ratio), and product type. If all above three factors result in one of pure MTS or pure MTO, the corresponding production strategy is adopted for the respected products. In the case of conflicting conclusions from above criteria, next step is skipped.

C. OPP location for adopted strategy

After deciding on production strategy for some of products, OPP can be located upon the selected strategy; in the case of MTS strategy, the first work center is determined as OPP and the last station relates to OPP in the case of MTO strategy.

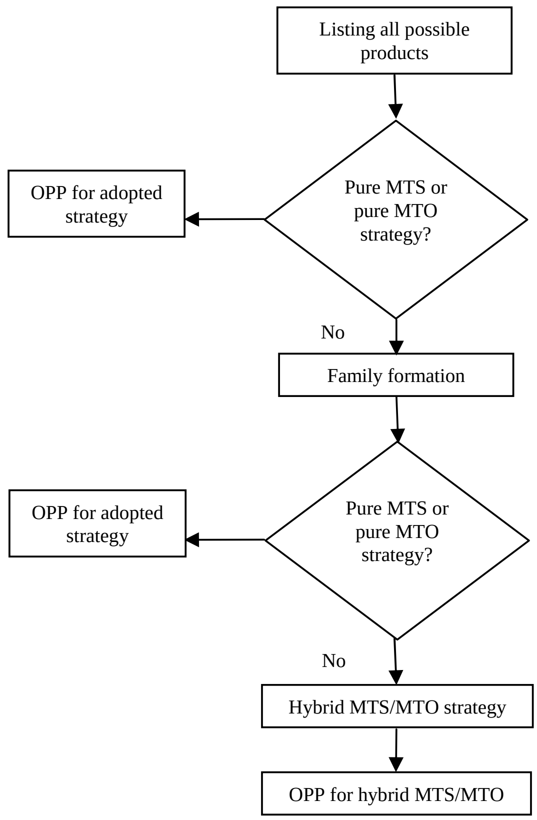

Fig. 1 Proposed structure toward order partitioning and OPP location

D. Family formation

With respect to the remaining products have not been decided, a hybrid strategy of MTS and MTO is adopted, because the introduced criteria result in conflicting production strategies. To have simpler and more controllable production structure, the remaining products are categorized into families of products. Different methodologies have been developed so far to form product families among which some are notable; descriptive procedures [14], mathematical programming [15], cluster-based procedures [16], and artificial intelligence [17]. However, mostly adapting family formation methodology to the subject of this paper is the recent method proposed by Galan et al. [18], since switching between production strategies might require reconfiguration of the production line. For a broad study on the procedure and the implementation of their method, readers are referred to Galan et al. [18].

E. Pure MTS or pure MTO for product families

With respect to the product families, applying pure MTS or pure MTO production strategies is evaluated regarding three mentioned criteria; demand volatility, P/D ratio, product type. Again, next step is skipped for the families for which production strategy is not specified.

F. OPP location for product families

Similar to the OPP location performed for individual products, OPP is determined for product families for which pure production strategy is decided. The first and the last workstations are selected as the OPP for MTS-based and MTO-based processed products, respectively.

G. Hybrid MTS/MTO production strategy

In the proposed model, products for which a pure MTS or pure MTO strategy is not decided are produced upon a hybrid MTS/MTO production strategy in which the OPP is located through the next step.

H. OPP location for remaining products

The most remarking role of OPP location rises in the hybrid MTS/MTO, since OPP is pre-defined in two other production strategies. OPP concept was firstly introduced in [19]. In this step, an ANP structure is developed to select the OPP for product families passed to this step.

ANP [5] was firstly introduced in 90s as a general form of the well-known Analytic Hierarchy Process (AHP) [20]. This methodology can model decisions with both qualitative and quantitative factors and judgments within an interrelated and dependent structure. To have a comprehensive study on differences between ANP and AHP, the comparative paper by Taslicali and Ercan [21] is recommended. Since the regarded factors are interrelated, ANP methodology is adopted to cope with the complexity of the OPP location.

TABLE I
OPP LOCATION FACTORS

Cluster	*Factor*	*Cluster*	*Factor*	*Cluster*	*Factor*
Market-related	Delivery time	Process-related	Processing time	Product-related	Holding cost
	Delivery reliability		Process flexibility		Backlog cost
	Product customization		Human resource flexibility		Risk of obsolescence

Alternatives of the developed ANP are the planning points along the production value chain. A planning point is a manufacturing resource or a set of manufacturing resources such as a workstation or a manufacturing cell that can be regarded as an entity from a production planning standpoint [3]. Among the planning points of the production line, bottlenecks are not suitable alternatives, because they yield longer delivery times and more backorder costs. Also, decision factors upon which the ANP structure is constructed are the ones presented in Table I with their categorized clusters structured in Fig. 2. Afterward, local comparisons of the elements of one cluster with respect to their influencing elements are performed as well as cluster comparisons similar to the local comparisons.

When comparisons are performed and comparison matrices are resulted, a method to elicit weights of each comparison element from comparison matrices must be applied. In this paper, Weighted Least Squares (WLS) method [22] is utilized to elicit relative weights of elements in a pair-wise comparison matrix. Supposing w_i the relative weight of element i, w_i/w_j corresponds to the relative importance of element i over element j in a perfectly consistent comparison matrix; i.e. $a_{ij}=w_i/w_j$ in which a_{ij} is the weight of comparison i over j in the relative pair-wise comparison matrix [23]. Supposing comparison elements as symmetric triangular fuzzy numbers, $a_{ij}=(l_{ij},m_{ij},u_{ij})$, (1) must hold. Moreover, relative weights of elements sum one, as depicted in (2).

$$l_{ij} \le a_{ij} = \frac{w_i}{w_j} \le u_{ij} \tag{1}$$

$$\sum_i w_i = 1 \tag{2}$$

To have higher level of consistency, the distance between a_{ij} and $m_{ij}=(l_{ij}+u_{ij})/2$ is minimized for all pairs of i and j. The optimization model with respect to (1)-(2) is presented by (3).

$$\begin{aligned} & Min \sum_{i,j} \left(w_i - a_{ij} w_j\right)^2 \\ & -w_i + l_{ij} w_j \le 0 && \forall i, j \\ & w_i - u_{ij} w_j \le 0 && \forall i, j \\ & \sum_i w_i = 1 \\ & w_i \ge 0 && \forall i \end{aligned} \tag{3}$$

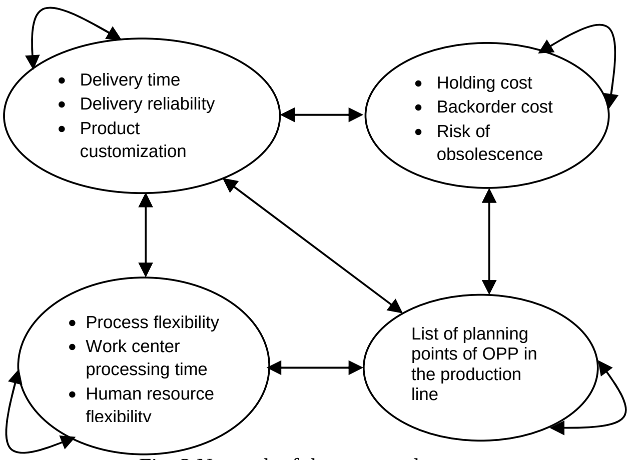

Fig. 2 Network of the proposed structure

Applying model (3) to all pair-wise comparison matrices results in relative weights of the elements in comparison matrices. Unweighted supermatrix is formed by putting together the obtained relative weights as blocks of a supermatrix and the resulted supermatrix is multiplied by the relative weights of clusters which are obtained from the cluster comparison matrix. The resulted supermatrix from the multiplication is the weighted supermatrix. Powering the weighted supermatrix until row convergence leads to limiting supermatrix based upon OPP is located.

IV. Case Study

In this section, we present the results of the proposed structure implementation in a real case study. The case study is an Iranian domestic appliance manufacturer that produces refrigerator and washing machine. Due to the tight competition in the market, the firm has to produce wide range of products to compete with domestic and international companies. The firm produces ten different kinds of refrigerator varying in size and eight models of washing machine varying in color and size. With respect to the predictability of the customers' demands, production of standard products and the P/D ratio larger than one, the management decided to manufacture all of these products in an MTS mode. Based on the change in the firm strategy, the management plans to produce new products and add some kinds of TV to its existing product portfolio.

The firm has no historical data about TV's demand trend and it is too difficult to predict the demands for TVs on a detailed level. Therefore, utilizing the MTS strategy cannot be taken into account for producing TVs. Furthermore, since the main revenue of the firm earned by selling refrigerators and washing machines, the bulk of the capacity is assigned to these products. Thus, the firm may be unable to deliver TV products within a short delivery time. More importantly, most of TVs have similar electronic components in form of sub-assembly parts. Therefore, the firm can produce sub-assembly parts based on a rough-cut aggregate demand data for all TVs and then manufacture the sub-assembly parts (MTS base). Then, the rest of TV is manufactured based on the customers' needs (MTO base). Moreover, the assessment revealed that it is not possible to produce all of products under pure MTS or pure MTO strategy with respect to different characteristics of TVs with other products. Overall, the firm decided to produce TVs under hybrid MTS/MTO production policy. To locate the OPP for TVs, we employed our proposed ANP structure to evaluate and choose the appropriate location of OPP.

In the considered firm, the existing products were grouped into five product families, called herein F1, F2, F3, F4 and F5. In the first two families, products belonging to each family are refrigerator with different sizes but having the same suppliers for their main assembly parts. Families F3 and F4 are related to washing machine and the last family bear all of the TVs.

The production system of the firm consists of four steps, two machining steps, one assembly center and one painting step. The assembly center includes five assembly lines, two lines for assembling refrigerator, two lines for assembling washing machine and one for TV. Two machining workstations, called WS1 and WS2, are located before the assembly lines. The WS1 is comprised of five machines including Eylet, Sequencers, Jumper, Axial and Radial insert machines. WS2 consists of two SMD continuous lines.

All of the products require WS1 and WS2 to complete their electronic board. Processing times of two machining centers are approximately 1.13, 6.73, 3.07, 2.76 and 7.68 minutes for product families F1, F2, F3, F4 and F5, respectively.

Set up times for machining processes are large and sequence dependent. Based on past experiences, the Jumper machine and one of the SMD's line act as the system's bottlenecks. In the proposed structure, therefore, these machines are not desirable for the OPP and are removed from the list of potential locations for OPP. The production process is reliable in quality and amount of output. Equipment is flexible enough to move around and also human resources are flexible in skills and able to work on any machine.

Holding cost for finished products is high and also, storage capacity is limited for semi-finished products. There is a good relationship between customers and firm and so the backorder cost is relatively low. The producer has to guarantee his customers a shelf life of at least 3 months.

The proposed ANP model for choosing appropriate location for OPP constitutes 9 criteria under three main criteria clusters and six main alternative locations (Eylet machine, Sequences machine, Axial machine, Radial machine, SMD machine, and Assembly machine). The pair-wise comparisons were made by taking the experts' opinion working in the firm. After using the geometric mean method to aggregate their evaluations, we constructed the required supermatrices.

The obtained overall weights from the limiting supermatrix are shown in Table II. Therefore, the most important factor is the delivery lead-time and the best alternative is the sixth one.

TABLE II
FINAL WEIGHTS OF CRITERIA AND ALTERNATIVES

Decision element	Overall weight	Decision element	Overall weight
Delivery lead-time	0.2667	Eylet machine	0.0346
Delivery reliability	0.1904	Sequences machine	0.0323
Product customization	0.1792	Axial machine	0.0263
Processing time	0.1342	Radial machine	0.0275
Process flexibility	0.1486	SMD machine	0.0318
Human resource flexibility	0.0710	Assembly machine	0.0517
Holding cost	0.0593		
Backlog cost	0.0487		
Risk of obsolescence	0.1147		

V. CONCLUSION AND FUTURE RESEARCH DIRECTION

With global markets, increasing global competition and shorter product life cycles, making decision on producing an item under MTO, MTS or MTS/MTO strategy is nowadays highly important and strategic. In this paper, we attempted to propose a new decision making structure to find solutions for two strategic issues in MTS/MTO systems including order partitioning and OPP location for each product family by considering the driving factors influencing these issues and fuzzy ANP as a decision making tool for finding the OPP locations. The results obtained from a real industrial case study show the efficiency of the proposed structure, especially in finding the OPP location.

To extend the presented model, developing new decision criteria including e.g. supplier related ones in a more completed HPP structure is highly recommended. In case of considering some quantitative data into the structure such as firm's production capacity and due dates, partitioning can be decided through an optimization model.

REFERENCES

[1] Y. Mu, Design of hybrid Make-to-Stock (MTS) - Make-to-Order (MTO) manufacturing system. M.Sc. Thesis, The University of Minnesota, 2001.
[2] M. Ebadian, M. Rabbani, F. Jolai, S. A. Torabi, and R. Tavakkoli-Moghaddam, "A new decision-making structure for the order entry stage in make-to-order environments," *Int. J. Prod. Econ.,* vol. 111, no. 8, pp. 351-367, 2008.
[3] J. Olhager, "Strategic positioning of order penetration point," *Int. J. Prod. Econ.,* Vol. 85, pp. 319-329, 2003.
[4] 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.
[5] T. L. Saaty, *Decision making with dependence and feedbacks: The analytic network process*, RWS Publications, 1996.
[6] L. A. Zadeh, "Fuzzy sets," *Inf. Control.,* Vol. 8, pp. 338-353, 1965.
[7] M. K. Omar and S. C. Teo, "Hierarchical production planning and scheduling in a multi-product batch process environment," *Int. J. Prod. Res.,* 2006.
[8] D. Corti, A. Pozzetti, and M. Zorzini, "A capacity-driven approach to establish reliable due dates in a MTO environment," *Int. J. Prod. Econ.,* vol. 104, pp. 536-554, 2006.
[9] S. H. Chang, P. F. Pai, K. J. Yuan, B. C. Wang, and R. K. Li, "Heuristic PAC model for hybrid MTO and MTS production environment," *Int. J. Prod. Econ.,* Vol. 85, pp. 347-358, 2003.
[10] S. Rajagopalan, "Make-to-order or make-to-stock: Model and application," *Manag. Sci.,* vol. 48, no. 2, pp. 241-256, 2002.
[11] 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.
[12] 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.
[13] J. Winker, and M. Rudberg, "Integrating production and engineering perspective on the customer order decoupling point," *Int. J. Oper. Prod. Manag.,* Vol. 25, no. 7, pp. 623-641, 2005.
[14] U. Wemmerlov, and N. L. Hyer, "Procedures for the part family/ machine group identification problem in cellular manufacturing," *J. Oper. Res*., vol. 6, pp. 125-147, 1986.
[15] A. Kusiak, "The generalized group technology concept," *Int. J. Prod. Res.,* Vol. 25, pp. 561-569, 1987.
[16] K. R. Kumar, A. Kosiak, and A. Vamelli, "Grouping of parts and components in flexible manufacturing systems," *Euro. J. Oper. Res.* 24, pp. 387-397, 1986.
[17] V. Venugopal, and T. T. Narendran, "Machine-cell formation through neural network models," *Int. J. Prod. Res*., vol. 32, pp. 2105–2116, 1994.
[18] R. Galan, J. Racero, and J.M. Eguia, "A systematic approach for product families' formation in reconfigurable manufacturing systems," *Robot. Comput.-Integr. Manuf.,* vol. 23, no. 7, pp. 489-502, 2007.
[19] S. Hoekstra, and J. Romme, *Integrated Logistics Structures: Developing Customer Oriented Goods Flow,* McGraw-Hill, London, UK, 1992.
[20] T. L. Saaty, *The analytic hierarchical process*, McGraw-Hill, New York, 1980.
[21] A. K. Taslicali, and S. Ercan, "The analytic hierarchy and the analytic network processes in multicriteria decision making: A comparative study," *J. Aeronaut. Space. Technol.*, vol. 2, no. 4, pp. 55-65, 2006.
[22] A. Chu, R. Kalaba, and K. Springarn, "A comparison of two methods for determining the weights of belonging to fuzzy sets," *J. Opt. Theory Appl.* Vol. 27, pp. 531-541, 1979.
[23] 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.