Acceptance/Rejection of Incoming Orders by a Fuzzy Analytical Hierarchy Process in Make-to-Order Environments

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Abstract: - Several incoming orders must be considered and evaluated in terms of many different conflicting criteria for acceptance/rejection in a Make-to-Order manufacturing system, leading to a large set of subjective or ambiguous data. Hence, an effective evaluation approach is essential to improve decision quality. In this paper, a Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method composed of two phases is utilized to determine the overall performance value and rank of the incoming orders. At the end, the effectiveness of the proposed model is demonstrated through a numerical example.

Keywords: - Make-to-Order System; Orders Acceptance/Rejection; Fuzzy Analytic Hierarchy Process.

1 Introduction

A manufacturing system can be defined as an arrangement of tasks or processes to transform a selected group of raw materials or semi-finished products into a set of finished products. There are different kinds of classifications for manufacturing systems [1]. From the viewpoint of the relationship between production release and order arrival, production systems can be classified into Make-To-Stock (MTS) and Make-To-Order (MTO). For a make-to-stock system, finished or semi-finished products are produced to stock according to forecasts of the demands. In a make-to-order system, work releases are authorized only in accordance with the external demand arrival.

In today’s business environment, a manufacturing organization that is able to fill customer orders quickly, as well as offering custom products, has the benefit of a competitive advantage. However, the requirement to a have high product diversity and quick response time places conflicting demands on the system [2]. As a result businesses that compete on response time concentrate on producing a limited portfolio of products. Items are produced ahead of demand and kept in stock, ready to be shipped upon having received of orders. Producing to stock becomes expensive when the number of products is large. It is also risky when demand is highly variable and/or products have short life cycles. Therefore, a significant increase in product diversity normally goes gradually with a shift from a MTS to a MTO mode of production. In the MTO mode, production is not begun until a customer order is placed.

Manufacturing system should have some characteristics in order to follow the MTO strategy. The advice currently available to aid these decisions includes articles by authors such as [3]. Muda and Hendry [4] proposed a new inclusive model based on an examination of a literature developed for MTO companies. The model comprises 14 principles, which offer a way to look at the strengths of the company and identify areas for potential improvements.

Literature review on production planning of MTO systems reveals that there are only a few numbers of research papers regarding the order entry stage. Hendry and Kingsman [5] have first considered the order entry stage in production planning structure of MTO systems. Hendry and Kingsman [6] have also taken input-output control systems as a technique to accept or reject new arriving orders.

In recent years, researchers have considered Workload Control (WLC) systems as a new approach for investigating the order entry stage. Zäpfel and Missbauer [7] describe WLC, sometimes referred to as “order review/ release”, as an extension of input-output control systems which allow the simultaneous control of input workload and capacity. The filed of WLC systems has been affected by so many researchers. Kingsman and

Hendry [8] have shown that the use of input-output control has a positive effect on performance measures such as lead time, queuing time and capacity utilization. Moreover Kingsman [9] has modeled WLC in a mathematical form to assist in providing procedures for implementing input-output control.

Motivated by the literature discussed above, this paper presents a decision making structure made up of two phases for acceptance or rejection of received orders at the order entry stage in MTO environments. The first phase manages the orders based on their due dates and the second phase controls the incoming orders by means of Analytical Hierarchy Process (AHP) methodology. Thus the rest of this section is a brief review of AHP literature.

Saaty [10] introduced AHP in response to the rare resources allocation and planning needs for the military in early 1970s. AHP has been widely used as a MCDM tool or a weight estimation technique in many areas such as selection, evaluation, planning and development, and so on. A presumption of AHP is consistency, or transitivity of preference; however, this may not always be true in real life [11]. The traditional AHP needs exact judgments. In addition, due to the complexity and uncertainty involved in real world decision problems, it is sometimes unrealistic or even impossible to perform exact comparisons. Since fuzziness [12] and vagueness are common characteristics in many decision-making problems, a good decision-making model needs to tolerate ambiguity or vagueness. The earliest work in fuzzy AHP appeared in van Laarhoven, & W. Pedrycz [13], which compared fuzzy ratios described by triangular membership functions. A number of methods have been developed to deal with fuzzy comparison matrices (i.e. [14]).

2 The proposed decision making structure

Among arriving orders, due to different constraints, the system is able to fulfill only some of them and the rest are rejected. Under this condition, MTO companies have to accept an optimal combination of arriving orders so that their profit and share in the competitive market are increased. Therefore, MTO systems need a decision making structure that helps them to manage arriving orders to meet these main criteria. In this paper, a comprehensive decision making structure is proposed to manage arriving orders at the order entry stage in MTO environments. The acceptance or rejection of incoming orders is firstly evaluated based on time factor. The accepted orders are then put under exact review by the proposed fuzzy AHP methodology.

To make appropriate decisions on arriving orders, they are classified into two groups based on their importance. In practice, companies may have different criteria to assign different priorities to arriving orders. In this paper, two important criteria, i.e., profit and market share are considered to prioritize arriving orders as follows: High priority orders that can make a significant profit and increase the company's market share; Low priority orders that can only increase the company's market share.

2.1 Acceptance/rejection of incoming orders based on due dates

We use the backward method proposed by Kingsman and Hendry [8] to calculate the operation completion date, earliest release date and latest release date of the orders.

$$\begin{aligned} &OCD_{n,i} = DD_i \\ &OCD_{n-1,i} = OCD_{n,i} - TWK_{n,i} - W_p \\ &OCD_{n-2,i} = OCD_{n-1,i} - TWK_{n-1,i} - W_p \\ &\vdots \\ &OCD_{1,i} = OCD_{2,i} - TWK_{2,i} - W_p \\ &LRD_i = OCD_{1,i} - TWK_{1,i} - W_p \\ &ERD_i = LRD_i - pool\ delay \end{aligned} \qquad (1)$$

where, n_i: Number of required resources for order i; DD_i: Due date of order i; ERD_i: Earliest Release Date of order i; $TWK_{r,i}$: Required processing time of order i on resource r; $OCD_{r,i}$: The Operation Completion Date of order i on resource r; LRD_i: Latest Release Date of order i (If the order is released to the shop floor after this time, it is impossible to meet its due date in regular time); $pool\ delay$: Potential released workload for all the accepted orders with material available waiting in the pool to be released to the shop floor which is preset by management. There are two types of accepted orders in MTO systems: orders that have been already confirmed and released to the shop floor, orders that have been confirmed but have not been yet released. These kinds of orders are waiting in a place called orders pool. W_p: Average waiting time per resource for an order with priority *p*.

In this section, we suggest an implicit model in order to accept or reject the incoming orders which is base on kingsman backward method. This model tries to accept or reject the incoming orders by rule of thump. The accepted orders are subsequently evaluated be the proposed methodologies. Consider that MAD_i is the Material Arrival Date needed for order i. Since the order entry stage is the medium term planning, the exact data does not need and an estimation of average value of MAD_i is acceptable based on the past performance of suppliers. Thus one of the following situations may happen:

- $MAD_i \leq ERD_i$: If the material arrival date is earlier than earliest release dates, then accept the incoming order. The new accepted order will be assessed by one of the methodologies.
- $ERD_i \leq MAD_i \leq LRD_i$: If the material arrival date is between ERD_i and LRD_i then the order is met with delay. In addition, the following alternatives may be used in order to accept the order:
  - Changing the $OCDs$ values: in order to keep the feasibility of DD_i the value of $MAD_i - ERD_i$ should be distributed over $OCDs$ values in order to achieve equal MAD_i and ERD_i. The new $OCDs$ values are derived from following equation: $OCD'_{r,i} = OCD_{r,i} - \frac{MAD_i - ERD_i}{n_i}$.
  - The values of W_p may be changed;
  - Increasing the new order priority;
  - The order may be delivered tardy (delaying the due date) or the incoming orders may be rejected.
- $MAD_i \geq LRD_i$: If MAD_i greater than LRD_i the order is probably met with a considerable delay. Thus, the following alternatives may be helpful:
  - Changing the values of $OCDs$ so that $MAD_i = LRD_i$: $OCD'_{r,i} = OCD_{r,i} - \frac{MAD_i - LRD_i}{n_i}$. But this alternative may cut the values of $OCDs$ considerably and hence resources will need high capacity in different periods.
  - The values of W_p may be changed;
  - Rejecting the low priority new order that is met with long delay or has a negative effect on production of other orders in the system;
  - The order may be delivered tardy or rejected.

2.2 The novel AHP-TOPSIS methodologies

As it is mentioned in the previous sections several new orders swarm into the manufacturing system, simultaneously. As a result finding a proper method to make decision on incoming orders is essential. AHP is a mathematical decision making technique that allows consideration of both qualitative and quantitative aspects of decisions. It reduces complex decisions to a series of one-on-one comparisons, and then synthesizes the results. When standard AHP is applied, it is strongly recommended that the number of criteria should not exceed 10 because the number of pair-wise comparisons needed in the analysis increases rapidly [10]. Therefore a fuzzy AHP methodology is suggested for ranking the accepted orders of the first phase. The ranked orders are then accepted based on the manufacturing system capacity by the algorithm presented in step 4. The final accepted orders will be placed at the end of the pool. The detailed implementation of the proposed model is as follows:

Step 1: Fuzzy pair-wise comparisons between accepted orders of the first phase are carried out

When making the comparisons, the questions focused are: (1) which of the two weights compared is a greater; and (2) how much greater. With these comparisons as the fuzzy input, the relative priorities of the weights are computed. These priorities reflect the decision maker's perception of the relative importance of the alternative.

Step 2: Establish the fuzzy judgment matrix

Step 2.1: Establish the fuzzy decision matrix

This matrix represents the relative performance (importance) of criteria. To build the fuzzy decision matrix a questionnaire is provided to get the experts' opinions. Hence linguistic variables are put into account. The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions.

It is not possible to make mathematical operations directly on linguistic values. That is, the linguistic scale must be converted into a fuzzy scale. The triangular fuzzy conversion scale given in Table 1 is used in the evaluation model of this paper. Fuzzy judgment matrix can be expressed as Eq. (2):

$$\tilde{A}=\begin{bmatrix}\tilde{A}_{11} & \tilde{A}_{12} & \dots & \tilde{A}_{1n}\\ \tilde{A}_{21} & \tilde{A}_{22} & \dots & \tilde{A}_{2n}\\ \vdots & \vdots & \tilde{A}_{ij} & \vdots\\ \tilde{A}_{n1} & \tilde{A}_{n2} & \dots & \tilde{A}_{nn}\end{bmatrix} \quad (2)$$

Since acceptance of an incoming order is profitable, we may consider acceptance of incoming orders as priority. Hence, we should carry out AHP analysis based on acceptance of incoming orders strategy. In other words, for each alternative compared to another alternative in terms of acceptance of the incoming order is gratifying then it should have a higher value.

Table 1. Triangular fuzzy conversion scale

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(1,1,1)	(1,1,1)
Equally important	(1,2,4)	(1/4,1/2,1)
Weakly more important	(2,4,6)	(1/6,1/4,1/2)
Strongly more important	(3,5,7)	(1/3,1/5,1/7)
Very strongly more important	(4,6,8)	(1/4,1/6,1/8)
Absolutely more important	(5,7,9)	(1/5,1/7,1/9)

Step 2.2: Establish the total fuzzy judgment matrix with $\alpha-cut$

A^l_α and A^u_α are the lower and upper bounds of the closed interval, respectively.

$$A_\alpha=\begin{bmatrix}[A^l_{11\alpha},A^u_{11\alpha}] & [A^l_{12\alpha},A^u_{12\alpha}] & \dots & [A^l_{n1\alpha},A^u_{n1\alpha}]\\ [A^l_{21\alpha},A^u_{21\alpha}] & [A^l_{22\alpha},A^u_{22\alpha}] & \dots & [A^l_{2n\alpha},A^u_{2n\alpha}]\\ \vdots & \vdots & [A^l_{ij\alpha},A^u_{1ij\alpha}] & \vdots\\ [A^l_{n1\alpha},A^u_{n1\alpha}] & [A^l_{n2\alpha},A^u_{n2\alpha}] & \dots & [A^l_{nn\alpha},A^u_{nn\alpha}]\end{bmatrix}$$

Step2.3. Establish the crisp judgment matrix

A^β_α matrix is the crisp judgment matrix which represents the degree of satisfaction of the experts on the judgment. In order to characterize the degree of the optimism of a decision maker, α should be fixed and then the index of optimism β can be set. A larger β indicates a higher degree of optimism, and vice versa. The index of optimism is a linear convex combination and can be defined as: $A^\beta_{ij\alpha}=(1-\beta)A^l_{ij\alpha}+\beta A^u_{ij\alpha}$

Thus the total fuzzy judgment matrix with $\alpha-cut$ and index of optimism β leads to the crisp pair-wise comparison matrix which we use in the next steps. It can be expressed as Eq. (3):

$$A^\beta_\alpha=\begin{bmatrix}A^\beta_{11\alpha} & A^\beta_{12\alpha} & \dots & A^\beta_{1n\alpha}\\ A^\beta_{21\alpha} & A^\beta_{22\alpha} & \dots & A^\beta_{2n\alpha}\\ \vdots & \vdots & A^\beta_{ij\alpha} & \vdots\\ A^\beta_{n1\alpha} & A^\beta_{2n\alpha} & \dots & A^\beta_{nn\alpha}\end{bmatrix} \quad (3)$$

Step 3: Alternative methods

Step 3.1: Eigenvalue method

Consider n elements to be compared, $C_1,C_2,\dots,C_n$ and denote the relative 'weight' (or priority or significance) of C_i with respect to C_j by a_{ij} and form a square matrix $A=(a_{ij})$ of order *n* with the constraints that $a_{ij}=1/a_{ji}$, for $i\neq j$, and $a_{ii}=1\ \forall i$. Such a matrix is said to be a reciprocal matrix. The weights are perfectly consistent if they are transitive, that is $a_{ij}=a_{ik}a_{kj}\ \forall i,j,k$. Information derived from pair-wise comparisons can be represented as a reciprocal matrix of weights (Eq. 4) which is perfectly consistent if the elements are calculated from exactly measured data.

$$A^\beta_\alpha=\begin{bmatrix}w_1/w_1 & w_1/w_2 & \dots & w_1/w_n\\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n\\ \vdots & \vdots & wi/w_j & \vdots\\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n\end{bmatrix} \quad (4)$$

For matrices involving human judgment, the condition $a_{ij}=a_{ik}a_{kj}$ does not hold as human judgments are inconsistent to a greater or lesser degree. It should be denoted that some inconsistencies can be expected and accepted. When A^β_α contains inconsistencies, the estimated priorities can be obtained by using the comparison matrix as an input and using the eigenvalue technique: $(A^\beta_\alpha-\lambda_{\max}I)W=0$.

Where, $\lambda_{\max}$ is the largest eigenvalue of matrix A^β_α; *I* is the identity matrix and *W* constitutes the estimation relative priorities. If the matrix does not include any inconsistencies, i.e. the judgments made by a decision maker have been consistent, *W* is the exact estimate of the priority vector with considering that: $\sum w_i=1$.

Saaty [15] has shown that $\lambda_{\max}$ of a reciprocal matrix A is always greater or equal to *n* (number of rows or number of columns). If the pair-wise comparisons do not include any inconsistencies, $\lambda_{\max} = n$. The more consistent the comparisons are, the closer the value of computed $\lambda_{\max}$ is to *n*. Based on this property, a consistency index, *CI*, has been constructed which is reflected in Eq. (5):

$$CI = (\lambda_{\max} - n)/(n-1) \tag{5}$$

CI estimates the level of consistency with respect to a comparison matrix. Then, because *CI* is dependent on *n*, a consistency ratio *CR* is calculated which is independent of *n*: $CR = CI / RCI$. It measures the coherence of the pair-wise comparisons. To estimate *CR*, the average consistency index of randomly generated comparisons, *RCI*, has to be calculated. *RCI* varies functionally, according to the size of the matrix (e.g. [10]).

As a rule of thumb, a *CR* value of 10% or less is considered acceptable [15]. Saaty [15] suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable and all or some of the comparisons must be repeated in order to resolve the inconsistencies of the pair-wise comparisons.

Step 3.2: An approximate method

In order to find the priorities from the pair-wise comparison matrix, an alternative method may be put into account. Consider that ψ_j returns the sum of the elements in each column. Thus the priorities are calculated as Eqs (6-8):

$$\psi_j = \sum_{i=1}^{n} A_{ij\alpha}^{\beta} \qquad j = 1,2,\ldots,n \tag{6}$$

$$A_{\alpha\ norm}^{\beta} = \begin{bmatrix} A_{11\alpha}^{\beta}/\psi_1 & A_{12\alpha}^{\beta}/\psi_2 & \cdots & A_{1n\alpha}^{\beta}/\psi_n \\ A_{21\alpha}^{\beta}/\psi_1 & A_{22\alpha}^{\beta}/\psi_2 & \cdots & A_{2n\alpha}^{\beta}/\psi_n \\ \vdots & \vdots & A_{ij\alpha}^{\beta}/\psi_j & \vdots \\ A_{n1\alpha}^{\beta}/\psi_1 & A_{2n\alpha}^{\beta}/\psi_2 & \cdots & A_{nn\alpha}^{\beta}/\psi_n \end{bmatrix} \tag{7}$$

$$\sum_{i=1}^{n} \frac{(\sum_{j=1}^{n} A_{ij\alpha}^{\beta}/\psi_j)}{n} = \sum_{i=1}^{n} W_i = 1 \tag{8}$$

Descending W_i scores provide a means to prioritize alternatives based on decreasing decision-maker preference, which may also be used as an estimate of the perceived relative value of each alternative. Considering the manufacturing system capacity, the ranked orders would be accepted by an algorithm given in Figure 1. The highly ranked orders are appropriate to be accepted. The accepted orders will be sited at the end of the pool and the system capacity will be updated. The following formula is used to compare the required capacity of an order with the available capacity of the system throughout the algorithm: $C^k = \sum_{r=1}^{R}\sum_{t=1}^{T} C_{rt}^{k}$.

where, C_{rt}^{i}: The require capacity of order i on resource r in period t; cap: Maximum available capacity during the planning horizon; $cap_{re.}$: Available capacity of the system evaluated by reducing the required capacity of the accepted orders from the maximum available capacity.

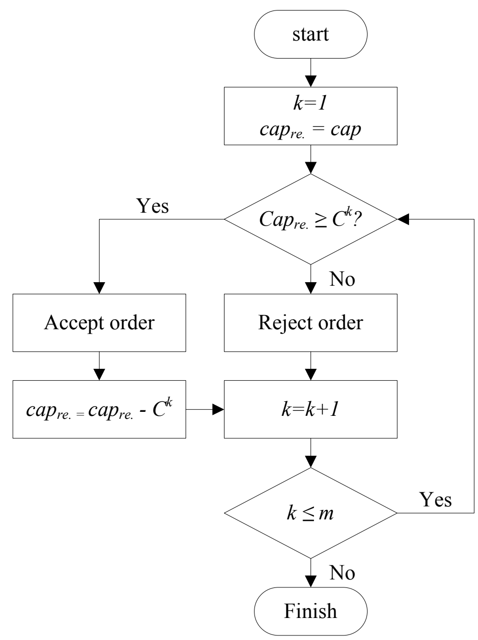

Fig. 1. The proposed algorithm for accepting the ranked orders

3 Numerical Example

In order to better understanding, in this section we present a numerical example. Suppose a firm is trying to make decision on incoming orders. Hence, the manager arranges a group of expert employees to solve the problem. A committee of four members is therefore installed to give advice as which products should be accepted. The committee decides to employ proposed decision-making structure. The incoming orders are first evaluated based on the kingsman backward method. As a result four orders are accepted. Then, the committee employs fuzzy AHP methodology. The first task of the committee is to evaluate the weight of each incoming order. Through pair-wise comparison, a fuzzy comparison matrix is constructed where each committee member only give a few judgments, i.e. not every cell of the matrices has four entries. The geometric mean method is adopted to generalize the experts' opinions. Consider the following fuzzy judgment matrix:

$$\begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \end{array}\overset{\begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array}}{\begin{bmatrix} (1\ 1\ 1) & (1/4\ \ 1/2\ \ 1) & (3\ 5\ 7) & (1/8\ \ 1/6\ \ 1/4) \\ (1\ 2\ 4) & (1\ 1\ 1) & (1\ 2\ 4) & (1/7\ \ 1/5\ \ 1/3) \\ (1/7\ \ 1/5\ \ 1/3) & (1/4\ \ 1/2\ \ 1) & (1\ 1\ 1) & (3\ 5\ 7) \\ (4\ 6\ 8) & (3\ 5\ 7) & (1/7\ \ 1/5\ \ 1/3) & (1\ 1\ 1) \end{bmatrix}}$$

Since the value of alpha and beta is determined by team members, they assumes that $\alpha = 0.4$ and $\beta = 0.6$. First of all, they establish the total fuzzy judgment matrix with $\alpha - cut$ and then calculate the crisp pair-wise comparison matrix with the optimism index β:

$$\begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \end{array}\overset{\begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array}}{\begin{bmatrix} 1 & 0.52 & 4.84 & 0.17 \\ 2.08 & 1 & 2.08 & 0.2076 \\ 0.2076 & 0.52 & 1 & 4.84 \\ 5.84 & 4.84 & 0.2076 & 1 \end{bmatrix}}$$

Finally they calculate the weight of each criterion: $weights = \begin{pmatrix} 0.202 & 0.1656 & 0.2499 & 0.3824 \end{pmatrix}$. Considering the weights, incoming orders are ranked. Due to the limit capacity of the firm, two highly ranked orders are accepted. Thus the forth and third orders are accepted.

4 Conclusion

Acceptance/Rejection of several incoming orders in terms of many different conflicting criteria for a manufacturing system leads to a large set of subjective or ambiguous data. Hence, an effective evaluation approach is essential to improve decision quality. Using MCDM models for order selection problems may be considered as efficient and suitable tools. An AHP method extended to fuzzy environments is utilized to determine overall performance value and rank of the incoming orders. At the end superiorities, rationalities, and the detailed implementation process of the proposed fuzzy AHP method is examined and demonstrated through a numerical example.

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