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Modeling ordered decision making in MTO/MTS production industries

Laleh Tashakori*

Department of Computer Engineering, Yazd Branch, Islamic Azad University, Yazd, Iran

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A B S T R A C T

This paper models the process of ordered product design decision making. The problem is formulated by introducing the notion of Quality Loss to quantify the loss of design freedom incurred by the decision makers in the later stages of a cross-functional decision process. In this context, the optimal order is the decision order with the lowest quality loss, whose characterization is one of the contributions of this paper. In this paper, we present a novel decision support system for order in a Make-to-Stock or Make-to-Order production environment. The proposed decision support system is comprised of six steps. The customers are prioritized based on a new method. In this paper, the idea of the algorithm "Knapsack" is used to prioritize customers. Finally, numerical experiments are conducted to show the tractability of the applied mathematical programming model.

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1. Introduction

Manufacturing companies often use different policies to meet their demands. Some response to their demands through finished products inventories that are called make-to-stock (MTS). Others fulfill an order only when it enters the system. These kinds of production systems called make-to-order (MTO) have to supply a wide variety of products, usually in small quantities. In such systems, the arrival of customers' orders is stochastic over time. The arriving orders usually require various routings and processing times through production facilities (Haskose et al., 2004). Among the arriving orders, due to various constraints, the system is able to fulfill only some of them and the rest are rejected. Under this condition, MTO companies have to admit an optimal combination of the arriving orders so that their profit and share in the competitive market increase. The main criteria to select this optimal combination in such environments are minimum price, short delivery time and high quality. The conflicts among these criteria make the production planning process too complicated. Production of high-quality orders usually increases their prices and delivery times. Also, fulfillment of orders with short delivery time needs extra resources, which increase their prices (Womack et al., 1991). Therefore,

* Corresponding author.
E-mail address: tashakkori@ymail.com (L. Tashakori)

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MTO systems, which are not able to predict the arrival time of their orders and have to deliver the arriving orders quickly, need a decision-making structure that helps them manage the arriving orders to meet these main criteria.

In recent years, much research on MTO environments has emphasized on delivery time criterion. This research is more about releasing orders to the shop floor and dispatching them through different workstations to decrease their delivery times. Although appropriate release time and accurate schedule of orders on the shop floor can lead to reduction of their manufacturing lead times and work-in-process (WIP), there is no guarantee that their delivery times are reduced (Kingsman et al., 1989). Instances of this research are presented by different studies (Philipoom & Fry, 1992; Belt, 1978; Irastorza & Dean, 1974). Complete review of such research has been offered by Wisner (1995). To decrease the delivery time, MTO companies need a planning stage to manage the arriving orders by considering the existing constraints before the job release and the dispatching stages. The decision problem of this stage is to examine whether the MTO system is able to deliver the arriving orders to customers with a low and competitive price and short delivery time or not. This examination is accomplished based on existing constraints. In the literature of hierarchical production planning in MTO environments, this stage is considered medium-term planning and is referred to the order entry stage (Hendryet al., 1998; Kingsman, 2000; Breithoupt et al., 2002; Hendry & Stevenson, 2006).

The purpose of this paper is to improve the production planning framework in MTO environments by proposing a new comprehensive decision structure for the order entry stage. The proposed structure leads to better management of the arriving orders by rejecting undesirable orders and determining reasonable prices and delivery times for the accepted orders. Since the decisions on the arriving orders are taken due to the current conditions of the system, the structure also leads to better planning of the job release and the dispatching stages.

In this model, the idea of a Knapsack algorithm is used. Suppose that the tourist wants to fill his/her Knapsack with the states to choose from a variety of devices that provide maximum comfort for him/her. The problem formulation begins by assigning numbers from *1* to *n* to devices and defining vectors of binary variables (Binary) ($j = 1,2, ... n$). That is to say, if object *j* is selected, otherwise when the tool is easily rate *j* provides the address and the weight and *c* is the size of a Knapsack. We take the issue of choosing between the binary vectors *x*, which is provided the limitation and the objective function takes the maximum value. We utilized this algorithm to present supplier selection model (Allahyari soeini et al., 2011; Allahyari soeini et al., 2012; Mokhtari et al. 2013; Tashakori et al., 2012; Mokhtari et al. 2012) and design decisions system with different production strategies (Tashakori & Arabsorkhi, 2015).

The structure of this paper is as follows: In the next section, the previous research on the order entry stage is presented. In Section 3, the proposed decision-making structure for the order entry stage is illustrated. This section consists of illustration of different steps of the structure and the developed linear programming models. Numerical experiments are presented in Section 4. In Section 5, to show the applicability of the proposed structure, an appropriate example presented. Finally, the advantages of the proposed structure and future research directions are discussed.

2. Literature review

The literature review on the production planning of MTO systems reveals that the number of research regarding the order entry stage is far fewer than the job release and the dispatching stages. Hendry and Kingsman (1989) first considered the order entry stage in the production planning structure of MTO systems. They emphasized that the key factor in success of MTO systems is the order delivery time management. Hence, before the job release and the dispatching stages, it is necessary to launch the capacity planning and control at the order entry stage. In this regard, a hierarchical input–output control was suggested across various stages of production planning including the order entry stage.

The primary objective of input–output control proposed first by Wight (1970) is the synchronous control of inputs (i.e., customers' demands) and outputs of the system (i.e., the capacity). Hendry and Kingsman (1993) also suggested a method by means of an input–output control approach in order to accept or reject the new arriving orders. Since the delivery and manufacturing lead times depend on the total backlog (TB) and planned backlog (PB) (Plossl & Wight, 1973), they are controlled by means of defining predetermined minimum and maximum values for TB and PB. If the arrival of a new order causes TB or PB to violate the predetermined values, either the capacity is increased or the new order is rejected. Easton and Moodie (1999) introduced a technique that simultaneously optimizes pricing and lead time decisions for MTO firms with contingent orders. In recent years, the workload control approach (WLC) has been considered by researchers to investigate the order entry stage. This approach is an extended input–output control approach, in which the amount of input workload and the capacity are controlled, simultaneously.

In this regard, three relatively different approaches have been introduced by Bertand and Wortmann (1981), Bechte (1988), and Kingsman et al. (1989). A comprehensive review of the WLC approach has been accomplished by Breithoupt et al. (2002). By means of simulation, Hendry et al. (1998) showed that in comparison with systems without control, the use of WLC at the order entry stage leads to decrease in manufacturing lead times of orders. Kingsman and Hendry (2002), using simulation of a real job shop at Lancaster University, showed that the use of input–output control has a positive effect on performance measures such as lead time, queuing time, and the capacity utilization in comparison with the use of input control alone and also a system without control. Kingsman (2000) also modeled WLC in a mathematical form to assist in providing procedures for implementing input and output control. It enables dynamic capacity planning to be carried out at the order entry stage. Haskose et al. (2004) modeled the WLC approach as a queuing network with limited buffer capacities for each workstation. Then, the obtained results were used to analyze issues in WLC. Hendry and Stevenson (2006) developed an aggregated load oriented WLC concept for the MTO industry referred to the Lancaster University Management School (LUMC) approach. A key characteristic of the LUMC approach is that it controls a hierarchy of backlogs beginning when a potential customer first makes an inquiry. Henrich et al. (2006) investigated the impact of grouping machines on the effective of the WLC approach within MTO job shops. They provided a starting point for a profound decision on grouping machines as well as on the control of the respective capacity groups.

With respect to the importance of the WLC approach for job shop practices, Land (2006) analyzed the sensitivity of the WLC approach to improve its performance. Land (2006) provided a number of new insights that improve the basis for setting parameters in WLC. The results have important consequences for implementations of WLC concepts in practice. In recent research, suppliers were also considered as a party of the MTO system that influence on prices and delivery times of orders. Cakravastia and Nakamura (2002) developed a model for price and due date negotiations between a manufacturer and its multiple suppliers to fulfill a single order from a customer. Calosso et al. (2003, 2004) discussed in detail the structure of a standardized negotiation process occurring in a multi-enterprise setting and presented three mixed-integer linear programming models that may be used by different parties involved.

Mortazavi et al. (2014) presented the model which has been integrated with a reinforcement learning algorithm and was applied to model a four-echelon supply chain that faces non-stationary customer demands. This approach leads to the development of a novel and intelligent simulation-based optimization framework, which includes a detailed simulation modeling of supply chain behavior. Li and Liu (2014) provided a simple but integrated stochastic network mathematical model for supply chain ordering time distribution analysis. Then the ordering time analysis model was extended so that the analysis of inventory level distribution characteristics of supply chain members was permitted. In addition, they presented a novel stochastic network mathematical model for order and cost distribution analysis (Li & Liu, 2012).

The primary disadvantage of previous studies is the lack of a comprehensive structure for the acceptance/rejection decision on the arriving orders and also selection of the best prices and delivery times for the accepted orders considering all relevant elements of the supply chain, such as suppliers, subcontractors, the MTO customers. Hence, in this paper, a comprehensive decision making structure is proposed to manage the arriving orders at the order entry stage of MTO environments by taking into account all affected parties of the supply chain. The proposed structure makes decision on the arriving orders regarding two criteria including price and delivery time. It is assumed that the production system produces high quality orders. Identifying and rejecting undesirable orders is an impressive stage. Some arriving orders may not increase the profit and market share of the company, they also bring chaos for the production system. The main chaos caused by undesirable orders is to delay the accepted orders due to the lack of the capacity taken by undesirable orders. Such a decision also causes the presented optimization models neither to be infeasible nor run for each arriving order. In this research, we focus on this stage to manage the arriving orders at the order entry stage of MTO systems efficiently.

3 The model presented

3.1Variables and parameters in the model

$d=1,2,\ldots,D$	Desired criteria for orders
$j=1,2,\ldots,J$	Products
$i=1,2,\ldots,I$	Raw materials
$B_d=[\, d_1, d_2 \ldots d_D]$	Customer's the value of the vector.
$W_d=[d_1, d_2 \ldots d_D]$	Organizations the value of the vector.
Cu	Auxiliary variable
M	The maximum investment for selection.
X	If $\mathrm{W_d} \leq \mathrm{Cu}$ then $\mathrm{X_d} = 1$ else $0 \leq \mathrm{X_d} < 1$
O	Orders
$\mathrm{MAX}_{\mathrm{Profit}_s}$	Total score which is obtained according to the algorithm for the decision.
$Profit$	The value obtained for The decision according to criteria d.

3.2Mathematical formulation

Step 1: Adoption of the initially important factors

In a multiple criteria evaluation problem, numerous criteria/attributes (in this paper we call aspects) and sub-criteria (in this paper we call factors) are needed to be considered. In this paper, the criteria are cited using Johansson et al.'s (1993) four key value metrics, which are service (S), quality (Q), cost (C), and cycle time (T), to show the CV. Johansson et al. (1993) indicated the value equation is as follows,

$$V = \frac{S \times Q}{C \times T}.$$

According to their viewpoints, any company should concentrate on improving the product quality and/or service, and at the same time reducing the cycle time and cost to the customer. Therefore, based on the four key value criteria mentioned above, all sub-criteria are first derived from academic, business and management publications, official Taiwanese sources, a detailed literature review (Christopher, 1998; Ding, 2009; Johansson et al., 1993; Lagoudis et al., 2006; Liang et al., 2007; Lu, 1997, 2000, 2003, 2007; Meyronin, 2004; Selviaridis et al., 2008; Stock & Lambert, 2001; Yilmaz & Bititci, 2006), and comprehensive interviews conducted by the author with main shippers of carrier-based logistics service providers (GSLPs). Hence, applying the concept of inductive method, four perspectives in the "Aspects hierarchy" and seventeen initially important factors in the "Factors hierarchy" are suggested, and their codes are shown in parentheses. They are categorized and subsequently explained in Fig. 1:

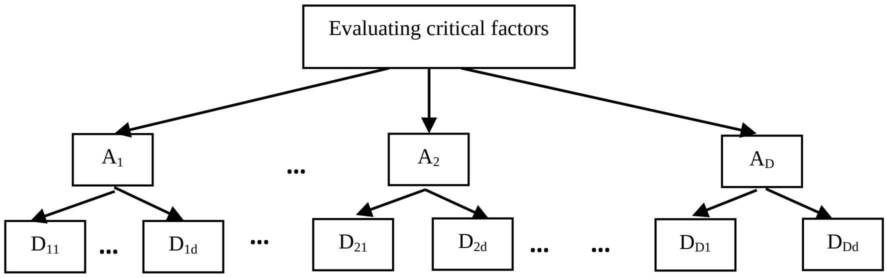

Fig.1. Hierarchy structure (Vector $D=[d_1,d_2,\ldots,d_D]$)

Service (A1)

Better service is associated with reaching more margin and bigger market share. Experience shows superior service deriving high customer satisfaction. Five initially important factors are summed to measure this aspect:

Providing diversity of value-added services (D11): Creating significantly added value for customers and providing various services for different customers are critical issues in logistics industry. It may be a business strategy or tactic to provide diversity services for serving a heterogeneous customer base.

Availability (D12): Each element of the logistics services will take advantage of the widespread adoption of any service availability via phone call, e-mail, web, and internet etc. Immediately availability of services will provide customers with gaining their needs and understanding.

Reliability (D13): This means the capability of a logistics service system to execute its functions in routine circumstances, as well as hostile or unexpected circumstances. The reliability in GSLPs especially emerged from the precise degree in the functions of storage, distribution, delivery, and consignment.

Providing adequacy of physical facilities and equipment (D14): Sufficient physical facilities and equipment, e.g. handling equipment, storage areas, and containers and chassis etc., play important role in complex market designed to reach rigorous market demands.

Increasing marketing channel and network (D15): The numbers of service node and channel, and marketing network may provide more convenient service for all customers. In addition, serving heterogeneous customers to provide customized services making it more flexible to customers.

Quality (A2)

Consumers may concentrate on the specification quality of a product, and they will compare with competitors in the marketplace. The conformance quality provided by the GSLPs might be considered by customers. The degree to which product should produce correctly, it means the movements of products can arrive safely, economically, and quickly from one location to another in this industry. Five initially important factors are summed to measure this aspect:

Improving customer satisfaction (D21): Experience show customer satisfaction is the most important factor influencing customer quality to reach customer retention and customer loyalty. Satisfying customer needs is necessary for obtaining customer acquisition to eventually gain profitability.
Safety (D22): It is the state of being safe when logistics activities are processed in the logistics center or warehouse. Controlling the safety is associated with high quality and low risk in handling shipments.

Accuracy and precision of shipments (D23): Accuracy is normally considered as the degree of veracity while precision is more associated with the degree of reproducibility and both of them are essential. Providing precise accuracy of shipments makes customer quality in high level to carry out.

Skills and knowledge of operating personnel (D24): All involved activities that make for the functionality to work well need good human resources to have an effective organization. All employees with superior skills will make the logistics operations more facile .

Capability of total quality service and integrated process management (D25): Does the service quality deliver the value to customers? Capabilities of total quality service provided by GSLPs will meet the customers' satisfaction. Developing a customer service network is essential. Of course, providing total quality service usually requires the supports from top managing layer. Subsequently, all shipments in warehouse to process logistics activities smoothly rely on having possession of capability of integrated process management. It makes logistics operations more fluent. Therefore, these two capabilities are possessed by the GSLPs; the customer quality will be satisfied accordingly.

Cost (A3)

In accounting, costs are the monetary value of expenditures for supplies, services, labor, products, equipment and other items purchased to use by a business. In economics, cost often means opportunity cost. Whatever in which fields, reducing cost is usually a common idea due to a firm can make a cheaper price. Hence, diminishing total logistics costs to customers can raise the value and benefits for customer. Three initially important factors are summed to measure this aspect:

Providing reasonableness of price (D31): Usually, the price includes a markup for profit over the expense of the services. Price comparison among competitors is often influenced by the customer based on evaluating the selection of GSLPs. Even price was uppermost as a critical impress on the buying decisions.

Reducing related operating costs of shipments (direct costs)(D32): These types of expenses are usually appeared on the core operational activities, e.g. marketing, warehousing and distribution. Operating costs are important parts of variable costs, in which they are mostly concentrated by customers. Selection of the best GSLP is accomplished based on the lower related operating costs of shipments among these competitors. Hence, reducing these types of expenses can attract customers to buy more services.

Reducing related overhead, charges and fees (indirect costs)(D33): Buyers prefer to pay money when they used related services, not pay overhead, surcharges and fees without using services, especially, which customers believe they do not use these services. Too much related overhead, charges and fees have negative effects for assessing the selection of GSLPs.

Time (A4)

'Time is money' is especially in evidence in today's globally competitive environment. Consumers in this field are increasingly sensitive on time aspect, while time or speed is deemed as a source of differentiation for firms. The 'cost of time' is referred to as a major influence of selecting GSLPs where the importance of timing is foremost. Time-based competition has become the main stream among the growth of time-sensitive logistics market. Therefore:

Reducing lead time of core logistics services (D41): Reducing the lead time can be achieved by shortening the logistics operation time (that is the time taken to complete the main core operational services from marketing, warehousing to distribution).

Implementing integrated logistics information system (D42): The applications highlight on helping a number of information technology (IT) and information system (IS), e.g. radio frequency identification (RFID), electronic data interchange (EDI), decision support system (DSS), and artificial intelligence (AI). The more automated the information system, the less opportunity on human error, which eventually leads to reduction of the operating time.

Reducing the non-value-adding time (D43): For any improvement, understanding the total activities of logistics processes is required. Eliminating out the non-value-adding activities and reducing the time spent on these useless and inefficient ones are vital.

Quick responsiveness (D44): The responsiveness of service should maintain a standard to specify the service is available at any time; it is possible that on an occasion service may be unavailable for very short time periods to permit maintenance or other development activity to happen. A quick and efficient responsiveness system service will reduce the complaint to arise.

Step 2: The weighted criteria

B and *W* vectors are creating criteria. Vector *W* is a company's current and products and vector B is associated with customers' current and their products.

Very Low=1 , Low=2 , Medium Low=3 , Medium=4 , Medium High =5 , High=6 , Very High=7

Step 3: Prioritization criteria

In order to express the criteria for selection, which will be B or W and the vector which are superior to selection criteria, for each criterion in the above vectors, we obtain ratio $\frac{\mathrm{B_d}}{\mathrm{W_d}}$ according to $\frac{\mathrm{B_1}}{\mathrm{W_1}} \geq \frac{\mathrm{B_2}}{\mathrm{W_2}} \geq \ldots \geq \frac{\mathrm{B_D}}{\mathrm{W_D}}$ and we evaluate the model. Bigger values represent higher desirability of criteria. If this ratio is equal for two criteria, the criterion is selected that the vector *D* is expressed earlier.

Step 4: Determination of investment rate

Variable *M* is the investment company for the production of policy. Being able to control the amount assets available for each stage, we use the variable *Cu*. $\mathrm{X_d}$ is the control variable. If $W_d \leq Cu$ then $X_d = 1$, otherwise $0 \leq X_d < 1$. Variable *Profit* shows the number of points in each stage. For each product to be resolved under the model with initial values we have,

$$\mathrm{X_d} = 0, \mathrm{Profit}=0, C_u = M \,, \qquad M = \sum_{d=1}^{D} B_d \tag{1}$$

Firms normally determine the capital according to market conditions and existing competitors according to Eq. (1).

Step 5: Get profit according to the investment rate

Until the point of assets is lower than the criteria case ($W_d \leq Cu$) will be established we repeat the following,

$$\sum_{D} \mathrm{Profit} = \mathrm{Profit} + \mathrm{W_d} \tag{2}$$

$$\mathrm{X_d} = 1 \qquad \forall d \tag{3}$$

$$\mathrm{Cu} = \mathrm{Cu} - \mathrm{B_d} \qquad \forall d \tag{4}$$

$$\mathrm{X_d W_d} \leq \mathrm{M} \qquad \forall d \tag{5}$$

where *Profit* is the total score the company acquires according to each criteria (Eq. (2)). Every time, we add score of criteria to *Profit*, we will consider $\mathrm{X_d} = 1$ to control the situation of algorithm (Eq. (3)). After reviewing the criteria, we will lower its criteria score from total assets (Eq. (4)). We use the Eq. (5) to control measures.

Step 6: Final Profit

$$\mathrm{X_d} = \mathrm{Cu} / \mathrm{B_d}, \tag{6}$$

$$\mathrm{MAX_{Profit}} = \mathrm{Profit} + \mathrm{X_d} \times \mathrm{W_d}. \tag{7}$$

At this stage, we will review next criteria only to know how much assets are available because we do not have enough investment for other criteria.

4. Case study

The case study is a manufacturer of moisture insulators. The company has two production lines in 8 hour work shift and two types of insulation: Powder insulation (P_1) and insulation coated with aluminum (P_2). Table 1 shows the received orders to the company.

Table 1
Received orders

Products	Price per unit (RSL)	O1	O2	O3	O4
P_1	32000	253	55	232	0
P_2	35000	1792	1710	0	2030

According to the proposed method, order 2 has more points, then it is on priority to supply. Orders 1 and 3 earn 96 points. Because quick response is the priority, we select orders according to size of order and delivery date agreed with the client. Because volume of order 3 is less than others and it is supported in a shift, then it is supported sooner than order 1. Therefore, the process of support order is this way: Order 2 (O_2 = 97.5), Order 3 (O_3 = 96), Order 1 (O_1 = 96) and Order 4 (O_4=95) (Table 2).

Table 2
Important criteria affecting decision

Criteria	W	B_1	B_2	B_3	B_4
D_{11}	5	6	6	5	6
D_{12}	6	6	5	6	5
D_{13}	7	6	6	7	6
D_{14}	5	5	4	4	3
D_{15}	4	4	5	5	4
D_{21}	7	6	6	7	6
D_{22}	7	7	7	7	7
D_{23}	4	4	5	3	4
D_{24}	3	4	5	4	4
D_{25}	5	5	5	6	5
D_{31}	7	7	7	7	7
D_{32}	6	5	4	5	5
D_{33}	7	5	5	5	5
D_{41}	7	7	7	7	7
D_{42}	4	5	5	5	5
D_{43}	5	5	5	5	5
D_{44}	7	7	7	7	7

5. Conclusions

In MTO systems, because there are wide varieties of products, low amount of standard products and the lack of possibility of appropriate forecasts, the production planning is more complicated than MTS systems. The arrival times of orders are stochastic over time and each new order often has a significant influence on profit and market share. Therefore, MTO companies need an efficient decision-making structure at the order entry stage in which the company can select an appropriate combination of the arriving orders.
This combination must lead to the increase the profit and the market share, significantly. In this paper, a new decision making structure has been proposed to select this combination. The proposed structure has the following advantages compared with the previous research studies:

- Since undesirable orders are determined and rejected through some special criteria, this leads to better planning and control for the rest of the arriving orders and also can prevent the proposed model from infeasibility.

- So far, many studies have been accomplished on the job release and the dispatching mechanisms as short term planning in MTO environments. Aggregation of the order entry and short-term planning stages within a hierarchical production planning structure in MTO companies will definitely improve the performance of the MTO companies. In this regard, the hierarchical production planning structure includes three main stages, i.e., the order entry stage, the order release stage and the dispatching stage.

- Nowadays, in addition to price and due date criteria, the quality of final products is also important for the customers. Since suppliers and subcontractors influence significantly on the quality of final products, hence quality criterion must be added to the criteria set to select the best set of suppliers and subcontractors.

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