A Decision Mathematical Model for Selection Production Strategy

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Abstract —Developing supply chain strategy plays an essential role to retain competition among companies. This paper investigates the decision about which items to make to stock and which ones to make to order based on a mathematical model minimize the difference between the costs of the two approaches. The production environment is characterized by multipleactivities such as purchasing, manufacturing, subassembly, and finished assembly. Through some numerical experiments the effect of different demand quantitates, customer delivery time and capacity limit are identified. The analysis provides an insight into the relationship between the supply chain costing and the strategic decision making.

Keywords—Make-tp-Stock (MTS), Make-to-Order (MTO), Hybrid, Supply chain cost.

1 INTRODUCTION

There are different kinds of production system. The two major categories including make to stock (MTS) and make to order (MTO). MTS production systems are mainly structured upon forecasts of demand mix and volumes. In contrary, production of an MTO product does not initiate unless an order is received. There are some advantages and disadvantages for both systems. One important advantage of MTS is the instant delivering order any time the customer need, but its disadvantages are the high cost of holding items until it is required, or the mismatching of the volumes need from the customer.

In order to take advantages of two MTS and MTO production system, hybrid MTS/MTO production systems have recently attracted academicians and practitioners. In a hybrid MTS/MTO production system, a segment of the production line is conducted upon demand forecasts (MTS segment) and the resulted unfinished work-in-process (WIP) inventory is completed through remainder of the line upon the received orders as in [1]. Many researchers neglect a product's BOM (Bill of materials) when represent the supply chain and represent it as a serial of workstation only. But the BOM plays a vital role in performing diverse activities in different departments of a manufacturing company, including production, inventory control, finance, purchasing, engineering and marketing as in [2]. The supply networks, or assembly networks are represented in this framework. The supply chain echelon could be classified into materials, subassembly and final assembly. Any material or component can be made to stock or order. The paper answers the following questions: which component should be made to order or stock? What factors can affect the decision? And what is the minimum cost of the supply network for the selected case? Therefore, in this paper, a mathematical model is used to measure the supply network cost in both cases MTS and MTO, and the minimum cost is selected as a decision with the constraint that the production time is less than or equal to delivery time.

This paper is structured as follows, in the next section; "Literature review" presents the related works on selection the production strategy MTS or MTO by different methods. "Proposed model" represents the proposed mathematical model of supply network cost. In "solution methodology" and "Numerical experiments", the solution methodology and conducted experimental results are presented, respectively. Finally, "Conclusion and future research directions" provides conclusions and directions for the future research.

2 LITERATURE REVIEW

Firms use different production strategies (e.g. make-to-order (MTO), make-to-stock (MTS), assembly-to-order (ATO), and engineer-to-order (ETO)) to produce their products. The primary goal of each manufacturing firm is to ensure long term profitability as in [3]. In MTO system, demands are responded when orders enter the system. MTO system is tailored for more expensive products which are highly customized. MTO is known to have short delivery lead time, capacity planning, order acceptance/rejection, and high due-date adherence. Vis-à-vis in MTS system, demand is responded through finished products inventories. MTS systems have lower variety of customization and usually less expensive products. MTS systems are claimed to have high fill rate, planning for inventories, defining lot size and forecasting of demand as in [4].

"Reference [5] proposed a method for analyzing one-stage systems by considering the demand as stochastic with limited interactions and capacity using queuing theory. And tried to address some questions such as how many goods should be stocked and how many made-to-order?". "Reference [6] worked on optimization of MTO and MTS policies. And considered a company in which multiple products were manufactured by a single machine with the first-come-first-served scheduling rule. And studied the effect of manufacturing (processing) time diversity on the MTO/MTS decision for backorder-cost cases of dollar per unit and dollar per unit per time. The results using M/G/1 queuing analysis, shows that holding cost rate, backordering cost rate and distributions of manufacturing times play an important role in MTO versus MTS decision. And concluded that reducing manufacturing time randomness leads to more MTO production". "Reference [7] made a comprehensive decision-making approach to select the appropriate method for producing the goods by prioritizing MTO products over MTS ones based on several criteria so that the production environment needed an impressive and helpful measurement structure to modify decision quality by using Analytical Hierarchy Process and Technique for order for order performance by similarity to ideal solution (TOPSIS) methods for partitioning of goods". An efficient decision making structure was developed at the order entry stage in hybrid MTO/MTS through a modeling the arriving. The model dealt with price and delivery time of arriving order as in [1]. A model was made for addressing the joint admission control and sequencing in a hybrid MTO/MTS system was a simple two classes (MTO/MTS) M/M/1 queue, making suggestion on how a company should react to an extra order, accept it or reject it and then on type of products and quantity of orders when signing a new contract to in the case of MTS. A structure of optimal admission control and sequencing policies to find the switching point in production threshold curve and acceptance threshold curves based on MTS inventory level and MTO queue size were designed as in [8]."Reference [9] proposed an extensive range of options on how to prefer MTO production over MTS ones with limited capacity, remarkable uncertainty due to demands, and unit production and setup times are inseparable elements in production system".

3 PROPOSED MODEL

A directed supply network is used to represent the BOM of a product as shown in 'Figure 1'. The network is composed from some nodes (components), and arrows. The nodes represent the raw materials, subassemblies, and finished product. The arrows connect nodes, and represent the activities as the transformation time of component which includes procurement, manufacturing (subassembly and assembly), and time to deliver to the customer. In order to use the critical path method, to measure the production time of supply network, all the nodes are linked with a dummy node S by dish lines at the beginning, and a terminal node E is formed to finish the activities. The most important evaluation criteria for most supply chain managers is the cost of the supply network, and the expected customer delivery time as in [10]. "Reference [11] said that the supply network cost is composed of physical cost and marketability cost. The physical cost includes all setup costs of production distribution and storage. Marketability cost includes all stock-out and asset specificity costs".

Assumptions

Here for simplifying the model and considering its characteristics, assumptions of the model are presented as the following:

- The supply chain is modeled as a network with nodes (components) representing raw materials, subassemblies, and finished product (only one finished product). Any material or component can be made to stock or made to order.

- Demand for the finished product is deterministic per time period.
- MTS demand, when out of stock, the lost sale costs are incurred for the finished product.
- MTS expected demand of component i, is calculated to cover the demand during the lead time plus some safety stockthat satisfies service level.
- MTS inventory control and replenishment of component i, is represented by an EOQ as the lot size that is ordered each time and OIas the order interval and MTS Ordering/setup production cost is calculated as the ordering/setup cost divided by the order interval, where, $OI_i = \sqrt{2S_i/h_iD_i}$
- MTS holding cost of component i is the difference between the expected demand and the demand quantity per time period.
- MTO lot size is as the demand quantityper time period, as there is a demand quantity ordered as the lot produced.
- MTO demand, when over capacity as the demand exceeds the production capacity, the order is rejected and an infeasible case is obtained.
- Each component i has a deterministic lead time forprocurement and/or production and/or delivery.
- Production capacity is limited to some quantitates produced per time period.

The following notation is taken from [12] by some different to be used in this paper:

N: the number of components (nodes).

i: The index of node(finished product, subassembly, and raw materials).

D_i: Average demand for component i per time period is denoted by an independent and identically variable from historical data.

$BOM(i,j)$: The quantity of component j required to produce one unit of component i.

S_i: Ordering/setup cost of componenti, procurement/production setup cost.

ED_i: Expected demand of componenti, where $ED_i = D_i L_i + SS_i$.

L_i: The deterministic procurement, subassembly, and assembly lead time of component i.

SS_i: Safety stock of component i, $SS_i = k\sqrt{L_i D_i}$,k: the service factor that satisfies service level "the probability of not having a stock-out".

H_i: Expected inventory cost of component i per time period is denoted by the difference between the expected demand and demand quantity.$H_i = h_i(ED_i - q_i)$, where h_i the holding cost per unit of component i

CAP :Capacity (maximum production) per time period.

q_i: Demand quantity of component i, per time period.

B_i: Expected lost sale cost of component i,$B_i = b_i(q_i - ED_i)$, where b_i: the lost-sale cost per unit of component i.

DT: Customer delivery time is the time from placing an order to receiving the finished product.

$\vec{X}$: A 0-1 sequence string that is used to represent MTS/MTO decisions of a node (component),

$\vec{X} = [x_1, x_2, \dots, x_{Nodes}], x_i \in \{0, 1\}, x_i = 0$ When component is MTS; $x_i = 1$ when component is MTO.

$PT(\vec{X})$:Production lead time of the finished product according to the nodes $(\vec{X})$ of supply network.

TC_i^{MTO}: Make to order cost of component i.

TC_i^{MTS}: Make to stock cost of component i.

3.1 MATHEMATICAL MODEL

The purpose of this paper is to find the suitable production strategy (MTS/MTO) for all the nodes of the supply network subject to two constraints, the customer delivery time constraint and the limited production capacity by using a mathematical mode to minimize the supply network cost.

Supply network cost = Ordering/setup cost+ Holding cost+ Lost sale cost.

Supply network cost (MTS) = $\sum_{i=1}^{N} TC_i^{MTS} = \sum_{i=1}^{N}(S_i + H_i + B_i)$

For MTO, there is no holding cost or lost sale cost so,

Supply network cost (MTO) = $\sum_{i=1}^{N} TC_i^{MTO} = \sum_{i=1}^{N}(S_i)$

Supply network cost (MTS) =

$$\sum_i^N TC_i^{MTS} = \sum_i^N \frac{S_i}{OI_i} + \sum_i^N h_i(ED_i - q_i) + \sum_i^N b_i(q_i - ED_i)$$

$\therefore$ Supply network cost $= \sum_{i=1}^{N} TC_i^{MTS} + \sum_{i=1}^{N}(TC_i^{MTO} - TC_i^{MTS})x_i$

$$= C + \sum_{i=1}^{N} w_i x_i$$

Where $C = \sum_{i=1}^{N} TC_i^{MTS}$ and is a constant, $w_i = (TC_i^{MTO} - TC_i^{MTS})$

So the proposed model can be formulated as follows:

$$\boldsymbol{min\ Z = \sum_{i=1}^{N} w_i x_i}$$

Subject to

$$PT(\vec{X}) \le DT,$$

$$PT(\vec{X})q_i \le CAP$$

$$x_i \in \{0,1\} \qquad (8)$$

The objective function 'equation (5)' minimize the difference between two cost of the supply network according to the selected strategy of different nodes, the two constraints 'equation (6) and equation (7)' the first one determines the assembly production time PT and it is equal to all the paths from the start node S to the end node E, which must be less than the customer delivery time. And the second is to ensure that the demand quantity must be less than or equal to the limited production capacity. 'Equation (8) is the binary variable x.

3.2 SOLUTION METHODOLOGY

The objective function with its constraints is a 0-1 integer programming model, by using the lingo programming. the inputs to the model are the BOM of the supply network with its quantities that required from raw materials and subassemblies to have one unit of the finished product, all raw materials, subassemblies, and finished product (nodes of supply network) have a data about the ordering/setup cost, and the holding cost per unit for a certain period. Also the lead time for each node is given, with its production capacity available per period time. Thes are entered in EXCEL sheet and processing in LINGO16 program to find the output result.

The outputs of the model is shown again in the EXCEL sheet, first the inventory levels (expected demand) for each node according to its lead time and a determined service level, second the length of the critical path, third the one/zero value for each node according to the solving of the model with its constraints, and finally the supply network cost for each selection MTS and MTO. Note 0 means that the selected production strategy of the node is MTS, and 1 means that the selected production strategy is MTO, so the final string of X is the selected strategies for all the nodes, for a mixed of 0 and 1, it is a Hybrid.

3.3 NUMERICAL EXPERIMENTS

3.3.1 NUMERICAL EXPERIMENT 1

Maruti Company assembled the general cycle model of Alto model car. The General Cycle model requires two subassemblies i.e. 1 unit of assembled cycle body and 1 unit of assembled wheel to produce one unit of finished product. Subassembly of cycle body requires 1 unit of handle bar, cycle frame, and seat as raw materials. Whereas Subassembly of wheel requires 4 units of wheels, tyre and tubes, 2 units of pedals and 1 unit of chain as raw materials. These raw materials are procured from different suppliers and hence it has a different procurement lead times. As shown in 'Figure 1', the supply network of the General Cycle. The data for the different nodes of the General Cycle's supply network is presented in Table 1.

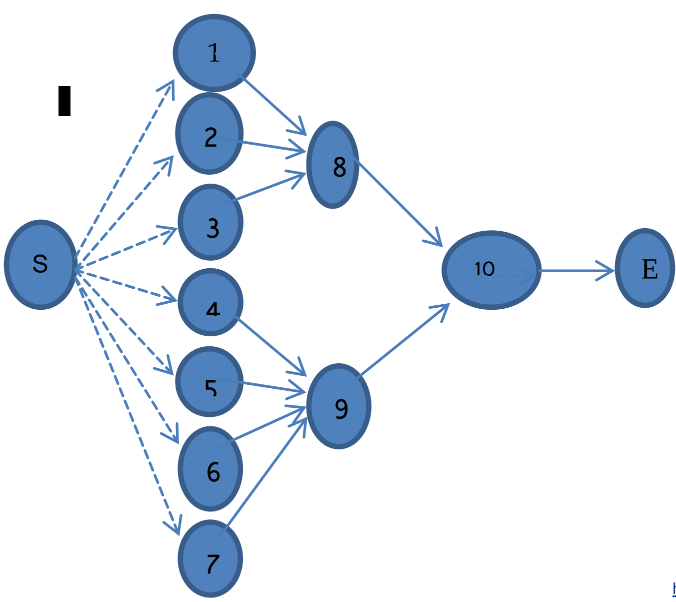

Figure 1. Supply network of General Cycle

Table 1 Data of the general cycle's supply network

Node	Name	BOM	L_i	S_i	h_i
1	Handle Bar	1	5	25000	2.5
2	Cycle Frame	1	5	40000	2.1
3	Seat	1	4	15000	2.3
4	Wheel	4	6	15000	3.3
5	Tyre&tube	4	7	30000	2.5
6	Pedal	2	4	20000	2
7	Chain	1	6	15000	1.5
8	Assembled cycle body	1	1	25000	5
9	Assembled wheel	1	1	25000	5
10	General cycle	1	1	40000	10

Result analysis

The test of the model on some scenarios with some different required demand quantities, and its customer delivery times with the above assumptions. The output of the model is (0/1) for each node shows the selected production strategy (MTS/MTO) subject to the two constraints.
A supply network cost is obtained for pure MTS, pure MTO, and for the mathematical model, also all the scenarios results are summarized in Table 2.

The critical path span time from starting node to termination node is equal to 9days, this is $PT(\overrightarrow{X})$ when all x_i for all nodes equal to 1, and the average demand per month is 10000units

Scenario 1
In scenario 1, the production strategy is Hybrid since the demand is greater than the average demand, and the customer delivery time is longer than the production lead time. In this scenario the Hybrid strategy with some nodes are MTO and the other nodes are MTS, since the long delivery time, is suitable for MTO but the large quantity of demand ensures that MTS has a minimum cost than MTO and so the suitable strategy with minimum cost and will deliver the required quantity on time is Hybrid.

Scenario 2
In scenario 2, the demand is medium and slightly less than the average demand, the customer delivery time is shorter than the

production time, and so pure MTO isn't a suitable strategy (infeasible). All nodes are MTO expect the raw material (node 5) because of its long lead time, so the Hybrid strategy is the best because of its minimum cost than pure MTS.

Scenario 3

In scenario 3, the demand is less than the average demand, and the customer delivery time is shorter than the production lead time, so the pure MTO is infeasible and the pure MTS has a high cost, so the hybrid strategy is suitable with a MTO finished product as its delivery time less than the customer delivery time.

Scenario 4

In scenario 4, the demand is greater than both the average demand and the limited capacity of production, although customer delivery time is less than the production lead time but MTO isn't a suitable strategy because of high demand which is more than capacity, the suitable strategy in this case is MTS.

Scenario 5

In scenario 5, the demand is a medium quantity according to the average demand, and the customer deliver time is less than the production lead time, so the pure MTO isn't a suitable strategy, the hybrid is the best with a minimum cost than pure MTS, as the critical path is selected to have the subassemblies and finished product are MTO.

Scenario 6

In In scenario 5, the demand is less than the average demand, and the customer deliver time is longer than the production lead time, so the pure MTO is a suitable strategy with a total minimum supply network cost.

Table 2 Different scenarios of general cycle and its result

Scenario	q_i	DT	Supply network cost			$\vec{X}$
			Pure MTS	Pure MTO	Math. model	
1	14000	12	232825	197000	187702	1001110111
2	8000	8	438699	Infeasible	260141	1111011111
3	2000	2	772299	infeasible	641187	0000000001
4	16000	12	238825	infeasible	238825	0000000000
5	6000	6	549899	infeasible	416704	0010010111
6	2000	15	772299	197000	197000	1111111111

3.3.3 SENSITIVITY ANALYSIS

3.3.3.1 THE PRODUCTION TIME AND THE DELIVER TIME

Every component in BOM has its lead time, the initial selection is based on the minimum cost and then the check of the delivery time constraint as it must be more than or equal to the production time. The variable $PT(x_i)$ may be equal to 0 indicates a MTS nodes or L_i indicates a MTO node, as scenario 2 the delivery time was 8days, and node 5 was 0 indicates a MTS procurement strategy this because its long lead time and the critical path from starting node to the terminal will exceed to delivery time. In scenario 1, although the delivery time is longer than the critical path time, but there are some nodes have a MTS procurement strategy, this because its MTS procurement cost was less than its MTO procurement cost due to the high ordering cost. For the intermediate nodes (subassembly nodes), its components may be as MTO/MTS when they are MTO, but a MTS subassembly node must have its components MTS also.

3.3.3.2 THE EFFECT OF COST FACTORS OF A COMPONENT

In this section the cost factors of a component are changed to examine its effect. The components are divided into two groups, and the cost factors and the production time are fixed in one group and they are varied in another group in order to find the relationship between the factors and the selected strategy with a minimum supply network cost.

The Tables 3and 4 below show the effect of changing these factors, the current state indicates in the central column in bold, by decreasing them in the columns before and increasing them in the columns after.

For node (8) in scenario 6, it was MTO, what will happen when its holding cost is decreasing or increasing? When the holding cost of node (8) decreases, it converts from MTO to MTS, and also its components (1, 2, 3, 4) indicates in bold are MTS also and the supply network cost increases $414635 as there are an addition holding inventory cost. But when it is increasing it remains MTO as it is the minimum cost and the supply network cost remains $197000.

Table 2 Effect of holding cost of node (8) factor with fixed variables$\boldsymbol{L_i = 1, S_i = \$25000}$

Node 8	$h_i = 1$	$h_i = 3$	$\mathbf{h_i = 5}$	$h_i = 7$	$h_i = 10$
$\vec{X}$	**0000**111011	**0000**111011	**1111111111**	111111**1**111	11111 11**1**11
Math model cost	4146350	197000	197000	197000	197000

For node (9), if the current state for the demand quantity 15000with8 days delivery time, node (9) is MTO and its componentsas in the central column in bold. What will happen when the setup cost of node (9) decrease or increase? Increasing the setup cost of it, it will convert to MTS and also its components and the supply network cost will increases to $225836. But if the setup cost decreases, node (9) remains MTO and its components are the same but the supply network cost will decreases to $179857.

However, more components are made to order when the holding cost is large. This is reasonable. The factors of production time and setup cost can be called as MTS factors; the others are named as MTO factors. When the MTS factors of a component are high, it is more likely to be made to order. However, when the MTO factors of an item are high, the item is more likely to be made to stock. The factors of the supply network are integrated, so some functions of the supply network should be considered from a view of the whole system.

3.3.3.3 THE EFFECT OF THE LIMITED PRODUCTION CAPACITY

As the production capacity is limited to 15000cars/ month, as in Scenario (4), the demand quantity is 16000 so MTO can't produce it as it increases the production capacity, and MTS is a suitable one with a high cost according to the lost sale quantities. To check the available capacity with respect to the required demand quantity, the capacity constraint as in 'equation (7)', the variablex_i must be zero if the demand quantity is more than the production capacity and this means that MTS is the suitable strategy. There are some demand quantities during some periods. Table 5 shows the expected demand and demand quantities during 12 months.

Table 5 demand quantities versus expected demand during 12 months

Month	q_i	ED_i
1	15100	10200
2	12000	10200
3	15000	10200
4	16000	10200
5	5000	10200
6	8000	10200
7	9000	10200
8	13000	10200
9	14000	10200
10	14500	10200
11	14900	10200
12	15500	10200

Conducting our model to find the minimum supply network cost for 12 months and measuring the percentage of utilization in each strategy, we relax the delivery time constraint, to find out the effect of limited production capacity on the selected strategy as shown in Table 6.

Table 4 Effect of set up cost of node (9) with fixed variables$\boldsymbol{L_i = 1, h_i = 5}$

Node 9	$S_i = 5000$	$S_i = 15000$	$\mathbf{S_i = 25000}$	$S_i = 35000$	$S_i = 45000$
$\vec{X}$	100**1010**111	100**1010**111	100**1010**111	100**0000**101	100**0000**101
Math model cost	179857	189857	199857	221875	225836

Table 6 Supply network cost and average utilization

Month	Pure MTS cost	Pure MTO cost	Math. Model cost
1	327499	Infeasible	196673
2	248816	197000	189329
3	235825	197000	187702
4	238825	Infeasible	238825
5	605499	197000	197000
6	438699	197000	197000
7	383098	197000	197000
8	230811	197000	197000
9	232829	197000	187702
10	234325	197000	187702
11	235525	197000	187702
12	237325	Infeasible	237325
Utilization	68%	59%	63%

When the demand quantity is more than the production capacity, MTO is infeasible, so the utilization of the production line decreases in case of MTO when there are many periods with a high demand quantity, the utilization can be measured as the average quantity produced per period time to the capacity and as more demand quantities are over capacity as more MTO is not efficient to utilize the capacity good.

3.3.2 NUMERICAL EXAMPLE 2

'Figure 2' represents the supply network for the notebook finished product. Table 7 gives the production lead time and other factors for each node. The average demand is 150/week**.**

Table 7 Data of supply network of notebook

Node	Name	BOM	L_i	S_i	h_i
1	R1	1	2	200	0.25
2	R2	1	3	20	0.4
3	R3	1	2	150	0.5
4	R4	1	1	150	1.5
5	R5	1	1	100	0.55
6	R6	1	1	25	0.75
7	R7	1	1	50	0.8
8	R8	1	1	100	1.2
9	R9	1	1	150	1.5
10	R10	1	1	140	1.75
11	SA1	1	1	250	2
12	SA2	1	1	280	2.2
13	A3	1	1	300	3

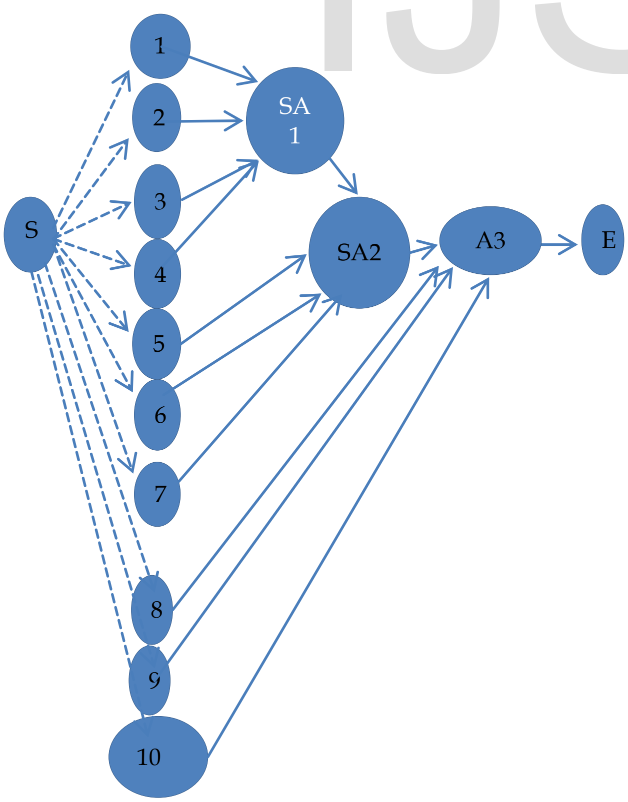

Figure 2 The supply network of notebook

We conducted some scenarios to find out the suitable strategy of every component of BOM of the notebook to find the minimum supply network cost within different segment of demand quantities and delivery time.

Table 8 Different scenarios of notebook demand quantities

Scen-ario	q_i	DT	Supply chain cost			$\vec{X}$
			Pure MTS	Pure MTO	Math model	
1	150	6	2111	2727	2111	0000000000
2	80	10	3227	2727	2526	0001011111111
3	200	8	1825	2727	1825	0000000000000
4	60	6	3545	2727	2560	0001011111111
5	20	8	4181	2727	2611	0101111111111
6	120	4	2588	2727	2438	000000101011

As shown in the previous scenarios of numerical experimental 1, as a small demand quantities are required as MTO is a suitable selected strategy if there are a long delivery time. Otherwise a Hybrid strategy is a suitable one with a minimum cost less than pure MTS strategy. But a large demand quantity with a small or long delivery time has a MTS as a suitable selected strategy.

CONCLUSION AND FUTURE WORK

The objective of the model is to choose the suitable production strategy according to the minimum supply network cost subject to the customer delivery time and the capacity limit. According some scenarios applied to the experimental numerical examples, the selected strategy is obtained from the proposed model. Such decisions are generally taken once every six months or every year. The familiar interface of Microsoft Excel makes the use of the tool even more attractive to enter the BOM with its quantities, lead time, and other cost factors. Then the processing with Lingo gives the total cost in both cases MTS and MTO, and gives the minimum cost with the considered constraints.

The positive effects of using this procedure are that a discussion can be started on demand variances and delivery time to different customers.

We used a deterministic approach with constant demand and limited capacity assumptions. Future models should aim at considering multiple products for determining the lot sizes and the MTO versus MTS option simultaneously.

Future research needs to be performed to find if and how market and demand structures and type of production capacities influence the order of decisions. In that we can also further explore if a step by- step approach has specific disadvantages as compared to an integrated decision model.

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