Journal of Quality Engineering and Production Optimization

Vol. 3, No. 1, PP. 1-12, 2018

A Batch-wise ATP Procedure in Hybrid Make-to-Order/Make-to-Stock Manufacturing Environment

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Abstract-- *Satisfying customer demand necessitates manufacturers understanding the importance of Available-To-Promise (ATP). It directly links available resources to customer orders and has significant impact on overall performance of a supply chain. In this paper, an improvement of the batch-mode ATP function in which the partial fulfillment of the orders is available will be proposed. In other words, in a hybrid make-to-order/make-to-stock manufacturing environment, the proposed model responds to customer's requests in 3 different ways; rejecting, fulfilling, and partial fulfilling. By using this procedure, the reliability of order fulfillment and the responsiveness of order promising will be enhanced. To evaluate the applicability of the proposed model, some numerical examples and sensitivity analysis are conducted. Results show that by applying partial fulfilment and penalty to backorders, the number of rejected orders and profit would be minimized and maximized, respectively.*

Keywords: *ATP, batch-mode ATP, partial fulfillment*

I. INTRODUCTION

Nowadays, it is crucial to design fast and reliable order promises in order to retain customers and increase market share (Fleischmann et al., 2015). Available-to-Promise (ATP) is an important concept in Supply Chain Management (SCM). The use of ATP in SCM means to set an available delivery date and quantity for a received order. For this purpose, different methods have been introduced in the literature. (Zhao et al., 2005; Xiong et al., 2003).

ATP is a kind of commitment limit for delivery, which is an interpretation of "delivery quotations." Delivery quotations are important concepts in SCM. ATP is used in different policies, for instance, Make to Stock (MTS) and Make to Order (MTO). Olhager and Prajogo (2012) discussed the main differences between MTO and MTS environments, comprehensively. They showed that the distinction between MTO and MTS firms was important when analyzing manufacturing and supply chain improvement initiatives. In case of using MTS policy, in which the concept of finished goods inventory exists, ATP is related to allocation of the inventory to an order and calculation of the delivery lead time. In case of using MTO policy, the lead time is determined based on the inventory level of usable parts, materials, and resources (Robinson & Carlson, 2007). By allocating materials and resources such as machines and workers based on forecasted demand, delivery dates are determined. In recent years, there has been a growing interest in hybrid Make to Stock (MTS) and Make to Order (MTO) production planning. Beemsterboer et al. (2016) examined the benefits of a hybrid planning approach without priority for either MTO or MTS.

Since the main purpose of ATP is determining quantity and due date, its solving algorithms can be classified as follows:

1) Quantity Quoting: the ATP tries to specify the quantity within the acceptance range with regard to the specified time.

2) Due-Date Quoting: the ATP tries to specify the delivery date, which falls into the time window, regarding the specified quantity.

Manuscript Received:10 -Oct-2015 and revised: 20-Sep-2016 *ISSN: 2423-3781*
Accepted: 24-Dec-2016

3) Quantity and Due-Date Quoting: specifying both order quantity and due date based on customer's specified ranges (Chen et al., 2001).

In the case that specified ranges of order quantities and/or due dates cannot be held for all orders, all three ATP mechanisms could provide suggestions for accepting a subset of orders.

Different methods of ATP are available such as Advanced ATP (AATP), real-time ATP, and batch-mode ATP (Chien-Yu et al., 2002; Pibernik, 2002). In batch-mode, requests of customers will be collected at fixed points in time (batching period). The length of the batching period might vary from minutes to weeks. The collected customer requests will be analyzed and each individual customer request will be confirmed at the end of each period (Tinnefeld et al., 2008). On the other hand, real-time systems allow a customer's request to be accepted and sourced based on existing inventory at the time of placing order. Specifications of orders are determined when they are received.

Robinson and Carlson (2007) stated that one important tool for providing a balance in tradeoffs between tangible profits, denied or rejected orders, and customer response time was the choice of proper batching interval size. One of the difficulties in batch-mode is adjusting the response time, which is mostly defined by batching interval that can be interpreted as a hamper.

In this research, former papers regarding ATP and its applications will be reviewed in the section on literature review.

II. LITERATURE REVIEW

The relevant literature on order promising and ATP can be broadly divided into ATP and AATP (Chen et al., 2001; Pibernik, 2005). In the study of Chen et al. (2001) some properties of AATP were expressed and ATP was compared with AATP. Pibernik (2005) provided a framework supporting the successful development and implementation of AATP in operations and inventory management. Cheng & Cheng (2011) formulated a mixed-integer programming model based on the concept of AATP inventory and fuzzy constraints on bid price. This study employed the max–min optimum approach and a genetic algorithm solver to find optimum bid price, delivery time, and quantity quotation. Rabbani et al. (2014) studied determination of AATP in a flow shop system regarding profitability and service level. Cheng and Wu (2015) attempted to solve a dynamic order promising problem in which the manufacturer processed customer orders on a batch basis. This decision process was repeated for every predefined batching interval and the current decision-making should take into account the previously committed orders. Rabbani et al. (2015) addressed AATP in mixed-model assembly line sequencing problems by prioritizing customers w.r.t different criteria. They studied the problem in MTO environment.

As previously mentioned, an ATP system provides product availability information as a tool for making a decision about customer's order request. ATP keeps track of the uncommitted portion of current and future available finished products. The concept of ATP is used in different environments. For instance, Chen-Ritzo et al. (2011) addressed the problem of rationing common components for available-to-promise scheduling among multiple products in a configure-to-order system with order configuration uncertainty. In the study of Tsai and Wang (2011), a generic three-stage model of multi-site ATP mechanism for assemble-to-order (ATO) manufacturing was proposed and tested on a local TFT-LCD manufacturer.

ATP falls into two categories: real-time and batch-mode. Tinnefeld et al. (2008) showed a conceptual plan for a real-time ATP database engine. Robinson and Carlson (2007) developed a model for real-time order promising. They constructed an event-driven model based on information availability that was flexible and modular.

In batch-mode, customer requests will be collected at fixed points in time (batching period). The length of the batching period might vary from minutes to weeks. The collected customer requests will be analyzed and each individual customer request will be confirmed at the end of each period (Tinnefeld et al., 2008).

Slotnick (2011) conducted a review of order acceptance and scheduling. He expressed that if all received orders were to be accepted, the problem would be reduced to the scheduling decision. If no scheduling is required, the problem is analogous to the knapsack problem. In almost all of the related papers, the manufacturer makes a decision about accepting or rejecting the order. In this paper, partial fulfillment as another option can be selected by the manufacturer in order to retain customers.

III. PROPOSED MODEL

Throughout this research, a model that determines which orders to accept, which ones to reject, and which ones to partially fulfill will be described. In this paper, hybrid make-to-stock (MTS) and make-to-order (MTO) manufacturing environment, which is consistent with many industries, is considered.

The main objective of the model is to maximize overall profit. The Overall profit includes two components. One is tangible profit, which consists in the difference between revenues and tangible costs including component costs. The other one consists in inventory holding costs for finished-products and modules and cost of remote sourcing. Overall profit is obtained from tangible profit by subtracting certain intangible penalties for order denial.

The time horizon as illustrated in Fig. (1) consists of three distinct sections, each representing a part of the production process as follows:

1. Production Scheduling (*T*-*N* time units)
2. Module Production (*N*-*n* time units)
3. Final Assembly (*n* time units)

The total time horizon is noted by T where t represents the period under consideration.

In this model, remote sourcing is available too.

A. Problem description and notations

The potential customer orders arrive within a specified customer's due date. The model specifies a schedule in which the quantities and due dates of the whole or partial deliveries for every arriving customer order are determined. The customer orders have to be assigned to different quantities, which are available in different parts of the time horizon. In the following, a mathematical model for generating order quantities and due dates for a given set of potential customer orders, simultaneously, is proposed.

B. Assumptions

1- If the order will be fulfilled in the first delivery or as a partial delivery, the maximum quantity which the customer requested (d_{ik}^{o}) must be delivered.

2- The first part can be divided into more than one part. For instance, if the order k is fulfilled in partial mode, we can deliver the first part in different loads during $\left[z_{ik}^{u}, z_{ik}^{o}\right]$.

3- The final assembly WIP, module WIP, and production schedule availability of module WIP are only available in predetermined periods, not in the whole T periods.

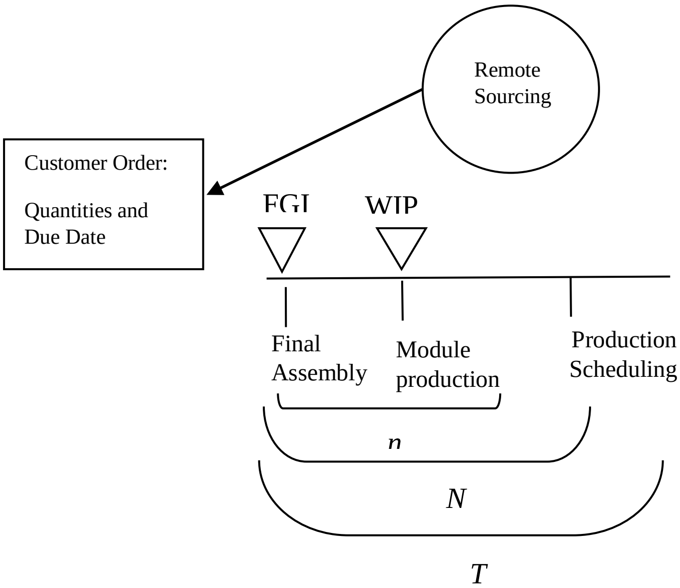

Fig 1. Time horizon

C. **Parameters**

The customer requires delivery of quantity d_{ik}^{o} of product i within the time window $\left[z_{ik}^{u}, z_{ik}^{o}\right]$; but in partial delivery mode, the minimum quantity d_{ik}^{u} can be fulfilled within $\left[d_{ik}^{u}, d_{ik}^{o}\right]$ and delivery of the rest will be at a point of time $t \geq z_{ik}^{o}$.

D. **Indices**

i	Different kinds of products
j	Different modules
O(k)	Set of potential customer orders
k ($k \in O$(k))	Every potential customer order

E. **Input parameters**

λ_{ik}	An integer decision variable equal to the quantity of product i of order k sourced from module WIP and production scheduling
BOM_{ij}	The number of modules j in product i
$IBOM_{ij}$	$1/BOM_{ij}$
Q_{FGI_i}	Quantity of FGI available for product i
Q_{FA_i}(t)	Quantity of FA WIP available for product i at time t
Q_{MOD_j}(t)	Quantity of module WIP for module j available at time t
Q_{PS_j}(t)	Quantity of production schedule availability for module j at time t
b_i	Price of product i
h_{1i}	Inventory holding cost for FGI
h_{2j}	Intermediate inventory holding cost for module j
F_{ik}	Contract penalties and losses of future profits if the customer switches to a different supplier
T_k	Additional handling and shipping costs associated with the second delivery (which have to be considered if u_{ik}^{2}(t) >0)
c_{FGI_i}	Cost associated with unpegged FGI of product i
c_{FA_i}	Cost associated with unpegged FA of product i
c_{MOD_j}	Cost associated with unpegged module WIP of module j
f_i	Cost of remote source per unit of product i
a_f	Fixed administrative cost of accepting an order
a_v	Variable administrative cost of accepting an order

r_f	Cost of rejecting an order
d_{ik}^{u}	Minimum order quantity of customer *k* for product *i*
d_{ik}^{o}	Maximum order quantity of customer *k* for product *i*
z_{ik}^{u}	Earliest date of delivery to customer *k* for product *i*
z_{ik}^{o}	Latest date of delivery to customer *k* for product *i*

F. Decision variables

$x_{ik}^{1}(t)$	Quantity of the first (partial) delivery at point of time *t* for order k of product i
$x_{ik}^{2}(t)$	Quantity of the second (partial) delivery at point of time $t \geq z_{ik}^{o}$ for order k of product *i*
u_{ik}^{1}	1; if the due date of the first partial delivery of order k for product i is t 0; else
u_{ik}^{2}	1; if the due date of the second partial delivery of order k for product i is t 0; else
v_{ik}	1; if order k for product i is fulfilled 0; else
$y_{FGI_{ik}}$	Quantity of order k for product i sourced from FGI
$y_{FA_{ik}}(t)$	Quantity of order k for product i sourced from Final Assembly WIP in period t
$y_{RS_{ik}}$	Quantity of order k for product i sourced from Remote Sourcing
$y_{MOD_{ijk}}(t)$	Quantity of module *j* pegged for product i of order k from Module Production WIP in period t
$y_{PS_{ijk}}(t)$	Quantity of module *j* pegged for product i of order k from Production Scheduling in period t

IV. MATHEMATICAL MODEL

A. Objective function

The objective function is maximizing the overall profit as mentioned in the previous section.

$$
\begin{aligned}
Max \quad Z= & \sum_{k}\sum_{i} b_i v_{ik} d_{ik}^{o} - \sum_{i}\sum_{k} z_{ik}^{o} h_{1i} v_{ik} y_{FGI_{ik}} - \sum_{i}\sum_{k}\sum_{t=1}^{n} (z_{ik}^{o} - t) h_{1i} y_{FA_{ik}}(t)\, v_{ik} \\
& - \sum_{k}\sum_{i}\sum_{j}\sum_{t=n+1}^{N} (z_{ik}^{o} - t) h_{2j} y_{MOD_{ijk}}(t) - \sum_{k}\sum_{j}\sum_{t=N+1}^{T} (z_{ik}^{o} - t) h_{2j} y_{Ps_{ijk}}(t) \\
& - \sum_{i}\sum_{t=z_{ik}^{o}}^{T}\sum_{k} T_k u_{ik}^{2}(t) - \sum_{k}\sum_{i} F_{ik}(1 - v_{ik}) - \sum_{k}\sum_{i} f_i . y_{RS_{ik}} \\
& - \sum_{i}\sum_{k} c_{FGI_i} y_{FGI_{ik}} - \sum_{i}\sum_{k}\sum_{t=1}^{n} c_{FA_i} y_{FA_{ik}}(t) - \sum_{i}\sum_{j}\sum_{k}\sum_{t=n+1}^{N} c_{MOD_j} y_{MOD_{ijk}}(t) \\
& - a_f \sum_{i}\sum_{k} v_{ik} - a_v \sum_{i}\sum_{k} d_{ik}^{o}(v_{ik}) + r_f\,(ik) - r_f \sum_{i}\sum_{k} v_{ik}
\end{aligned}
\tag{1}
$$

In the first term of the objective function, the entire income of the demands sales carried out is taken into account. The second, third, and fourth lines refer to inventory holding costs. The first term of the fifth line refers to additional handling and shipping costs resulting from partial deliveries and the second term accounts for penalties and the loss of future profits of order denial. The first term of the sixth line accounts for the cost of product that is sourced remotely. Line 7 describes the corresponding production costs. In the first and second terms of the eighth line, fixed and variable administrative costs (such as setup cost) for accepting an order are accounted for. The fixed and variable costs of rejecting an order are considered in the last term.

B. Constraints

$$\sum_{t=n}^{N} IBOM_{ij} \cdot \mathrm{y}_{MOD_{ijk}}(\mathrm{t}) + \sum_{t=N+1}^{T} IBOM_{ij} \cdot \mathrm{y}_{ps_{ijk}}(\mathrm{t}) = \lambda_{ik} \qquad \forall i,j \qquad (2)$$

$$\sum_{k} y_{FGI_{ik}} + \sum_{k}\sum_{t=1}^{n} y_{FA_{ik}}(\mathrm{t}) + \sum_{k} y_{Rs_{ik}} + \sum_{k}\lambda_{ik} - \sum_{k} d^{u}_{ik} \cdot \mathrm{v}_{ik} = 0 \qquad \forall i \qquad (3)$$

$$x^{1}_{ik}(\mathrm{t}) \geq \mathrm{d}^{u}_{ik} \cdot \mathrm{u}^{1}_{ik}(\mathrm{t}) \qquad \forall i,k \ ;\ t \in [1,\mathrm{T}] \qquad (4)$$

$$x^{1}_{ik}(\mathrm{t}) \leq \mathrm{d}^{o}_{ik} \cdot \mathrm{u}^{1}_{ik}(\mathrm{t}) \qquad \forall i,k \quad t \in [1,\mathrm{T}] \qquad (5)$$

$$\sum_{t=z^{u}_{i}}^{z^{o}_{i}} x^{1}_{ik}(\mathrm{t}) + \sum_{t=z^{u}_{i}+1}^{T} x^{2}_{ik}(\mathrm{t}) = d^{o}_{ik} v_{ik} \qquad \forall i,k \qquad (6)$$

$$x^{2}_{ik}(\mathrm{t}) \leq (\mathrm{d}^{o}_{ik} - x^{1}_{ik}) u^{2}_{ik}(\mathrm{t}) \qquad \forall i,k \qquad (7)$$

$$\sum_{t=z^{u}_{ik}}^{z^{o}_{ik}} u^{1}_{ik}(\mathrm{t}) = \mathrm{v}_{ik} \qquad \forall i,k \qquad (8)$$

$$\sum_{t=z^{o}_{i}}^{T} u^{2}_{ik}(\mathrm{t}) \leq 1 \qquad \forall \mathrm{i,k} \qquad (9)$$

$$\sum_{k} y_{FGI_{ik}} \leq Q_{FGI_{i}} \qquad \forall i \qquad (10)$$

$$\sum_{k} y_{FA_{ik}}(\mathrm{t}) \leq Q_{FA_{i}}(\mathrm{t}) \qquad \forall i,t \qquad (11)$$

$$\sum_{k}\sum_{i} y_{MOD_{ijk}}(\mathrm{t}) \leq \mathrm{Q}_{MOD_{j}}(\mathrm{t}) \qquad \forall j,t \qquad (12)$$

$$\sum_{k}\sum_{i} y_{Ps_{ijk}}(\mathrm{t}) \leq \mathrm{Q}_{Ps_{j}}(\mathrm{t}) \qquad \forall j,t \qquad (13)$$

$$u^{2}_{ik}(\mathrm{t}) = 0 \qquad \forall i,k \quad t \notin \left[z^{o}_{ik}, T\right] \qquad (14)$$

$$u^{1}_{ik}(\mathrm{t}) = 0 \qquad \forall i,k \quad t \notin \left[z^{u}_{ik}, z^{o}_{ik}\right] \qquad (15)$$

$$u_{ik}^{1}(t) \in \{0,1\} \qquad \forall i,k \quad t \in \left[z_{ik}^{u}, z_{ik}^{o}\right] \tag{16}$$

$$u_{ik}^{2}(t) \in \{0,1\} \qquad \forall i,k \quad t \in \left[z_{ik}^{o}, T\right] \tag{17}$$

$$v_{ik} \in \{0,1\} \tag{18}$$

In sourcing a product, by using constraint (2), we will allow not only WIP, but also production scheduling to be used. Constraint (3) ensures that demand is completely satisfied. It guarantees that the entire order will be fulfilled without exceeding the requested quantity. Constraints (4) and (5) ensure that the quantity of the first partial delivery is within the given interval. By using constraint (6), we will be sure that the quantity which is demanded by each customer for each product will be fulfilled. Constraint (7) links variable $u_{ik}^{2}(t)$ with $x_{ik}^{2}(t)$; clearly, according to the equation, if $u_{ik}^{2}(t) = 0$, then the second partial delivery cannot take place at the point oft and $x_{ik}^{2}(t)$ will be zero. Thus, the amount of the second part is zero. Constraint (8) clarifies that if order k for product i is accepted ($v_{ik} = 1$), $u_{ik}^{1}(t)$ will be 1 and vice versa. Constraint (9) is obvious according to the range of values $u_{ik}^{2}(t)$ can accept. Constraints (10-12) ensure that product is not over-promised. These constraints allow orders to be fulfilled according to the capacity of currently unpegged finished goods, work-in-process, or production scheduling

V. EXPERIMENTAL RESULTS

To validate the proposed model and solution method, some numerical experiments are conducted and the results are reported in this section. Sizes of the test problems are illustrated in Table I and value of each parameter is generated randomly (using the uniform distributions specified in Table II).

CPLEX solver is used for solving the proposed model. In the following, results for the first test problem are explained in detail. Table III shows the results of the first product in the mentioned test problem.

TABLE I. The size of test problems

Test Problem	No. of products	No. of customer orders	No. of time periods	No. of modules
P_1	10	30	10	4
P_2	15	50	15	6
P_3	20	70	15	7
P_4	25	100	20	8
P_5	30	150	20	8
P_6	30	200	20	10

TABLE II. The source of random generation of some parameters

Parameters	
price	Uniform ~(20000,30000)
inventory holding cost for FGI	Uniform ~(75,85)
cost associated with unpegged FGI of product	Uniform ~(450,650)
cost associated with unpegged FA of product	Uniform ~(450,650)
cost of remote source per unit of product	Uniform ~(300,400)
fixed cost of accepting an order	20
variable cost of accepting an order	10
cost of rejecting an order	40

TABLE III. The results for product a1

Parameters	
price	Uniform ~(20000,30000)
inventory holding cost for FGI	Uniform ~(75,85)
cost associated with unpegged FGI of product	Uniform ~(450,650)
cost associated with unpegged FA of product	Uniform ~(450,650)
cost of remote source per unit of product	Uniform ~(300,400)
fixed cost of accepting an order	20
variable cost of accepting an order	10
cost of rejecting an order	40

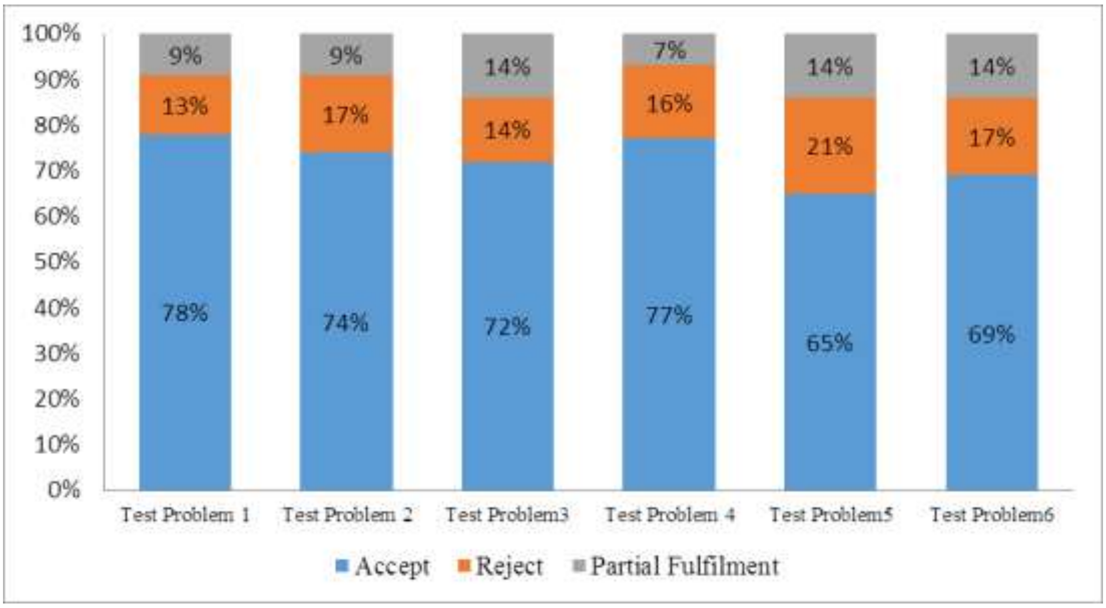

Fig 2. The percentages of different modes in batch-mode ATP

As shown above, by applying partial fulfilment, some orders can be accepted, instead of rejecting them, in the mode. Therefore, satisfaction of customers, which is one of the goals of this model, can be reached. The whole results are depicted statistically in Fig (2).

VI. SENSITIVITY ANALYSIS AND MODEL VALIDATION

To investigate the performance of partial fulfilment in batch-mode ATP, the fixed and variable costs of rejecting an order are changed and assigned higher values. As in the previous section, the results only for product 1 in the first test problem are shown in Table IV.

Obviously, the number of rejected orders gets minimized; the results are depicted simultaneously in the last part of Fig (3).

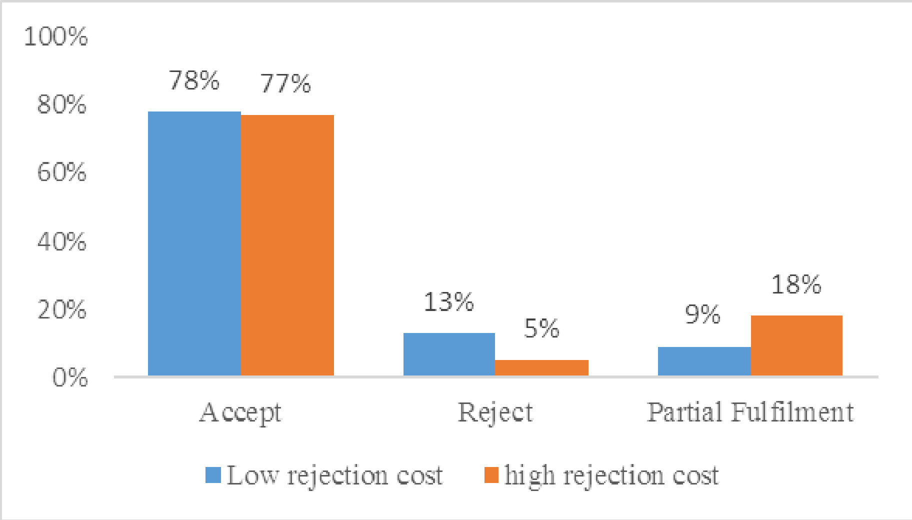

Fig 3. The percentages of different modes in batch-mode ATP when rejection cost is a high value

TABLE IV. The results for product 1

mode	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**
Accept		*	*	*		
Reject						
Partial-fulfilment	*				*	*
mode	1-7	1-8	1-9	1-10	1-11	1-12
Accept	*	*				*
Reject						
Partial-fulfilment			*	*	*	
mode	1-13	1-14	1-15	1-16	1-17	1-18
Accept	*	*			*	
Reject						
Partial-fulfilment			*	*		*
mode	1-19	1-20	1-21	1-22	1-23	1-24
Accept	*		*			
Reject						
Partial-fulfilment		*		*	*	*
mode	1-25	1-26	1-27	1-28	1-29	1-30
Accept		*	*			
Reject					*	
Partial-fulfilment	*			*		*

To validate the proposed model and assumption of considering availability of partial fulfilment, the test problems are solved in the case that only acceptance and rejection options are available for the manufacturer. Fig (4) shows that without considering partial fulfilment, rejection proportion will increase. By comparing the results of the test problems in these two cases, it could be inferred that profit of the manufacturer by considering partial fulfilment would increase Fig (5). Percentage of profit increase is calculated by Eq. (19).

$$Percentage\ of\ \ profit\ \ increase = \frac{Profit_2 - Profit_1}{Profit_1} \times 100 \tag{19}$$

where $Profit_2$ is objective function of the proposed mathematical model and $Profit_1$ is profit of the manufacturer when there is no partial fulfilment availability (corresponding variable of the partial fulfilment is fixed at zero).

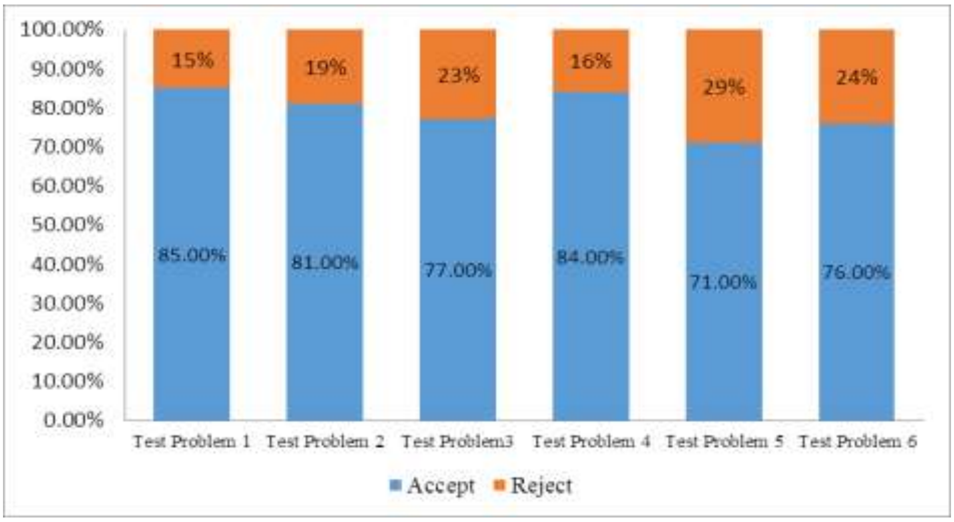

Fig 4. The percentages of different modes in batch-mode ATP when there is no partial fulfilment availability

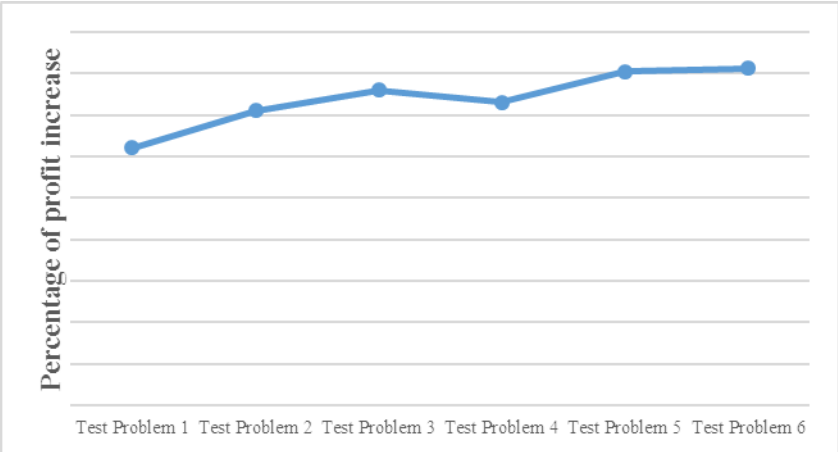

Fig 5. Percentage of profit increase by considering partial fulfilment availability

As shown in Fig (5), by increasing the number of orders, the effect of partial fulfilment strategy on increase in the profit is more significant. The required computational time to solve larger instances is increased considerably. Thus, for large-size problems, an appropriate metaheuristic algorithm must be developed.

VI. CONCLUSION

The main contribution of this study is applying partial fulfilment, which enhances the responsiveness of order promising. By applying partial fulfilment to the batch-mode ATP, some orders can be accepted partially, instead of rejecting them, to reach satisfaction of customers, which is one of the goals of the model. The statistical results showed that by applying partial fulfilment and penalty for backorders, the number of rejected orders would be minimized. This issue is more important when rejection cost is significantly large, which is closely the case in reality for many industries.

As discussed in section V, since partial fulfillment strategy would decrease number of rejected orders, when the rejection cost of the order is high, it would be a proper solution. In other words, instead of rejecting orders, we can answer the orders by two delivery parts so that the satisfaction of customers would be achieved. Also, by increasing number of orders and products, the increase in profit by considering partial fulfilment strategy is significant.

As a future research direction, an appropriate metaheuristic algorithm, such as genetic algorithm, must be designed for solving the proposed mathematical model for large-size problems. Another area of research is the inclusion of dynamic pricing in the model.

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