Fulfillment of Rush Customer Orders under Limited Capacity

Mohua Xiong, S. B. Tor, L. P. Khoo, Rohit Bhatnagar

Abstract: **Customer demand fulfillment is the business process within a company that determines how the customer demand is fulfilled. A rush order is the last minute customer order after the production plan of a company has been concluded. For these rush orders, appropriate and reasonable response is imperative as it could put strain on customer relationship and services. A good and positive response could help the company to build and retain its market share in today's highly competitive markets. A model aims at decreasing the product inventory cost is proposed in this paper. In this model, the prioritized fulfillment sequence of rush customer demands can be searched in terms of the product inventory cost. The paper focuses on two main issues: the available-to-promise (ATP) based fulfillment ability and the prioritized fulfillment of customer demands. For ATP based fulfillment, a dynamic bill-of-material (BOM) is proposed to handle the complicated issues of BOM, BOM explosion and production capacity. By means of dynamic BOM, material availability as well as production capacity can be taken into consideration simultaneously and efficiently. Two methods, mathematical optimization and heuristic algorithm, are constructed and elaborated on in the second issue. The proposed model allows companies to prioritize customer rush orders in terms of product inventory cost.**

Keywords: **Customer demand, Production capacity, Material availability, Dynamic BOM, Available-to-promise**

I. INTRODUCTION

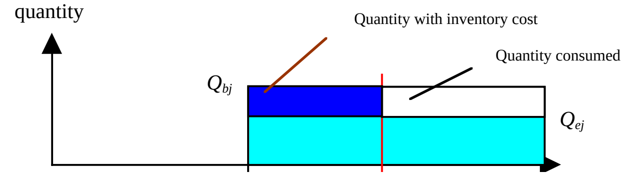
Customer demand fulfillment is the business process within a company that determine how the customer demand is fulfilled[1]. It is one of the very important customer services for a company and strongly influences the order lead-time and the on time delivery[2]. Through delivering good customer services, a company is likely to have more customer orders, and then able to maintain and increase its market shares.

Customer orders or demands trigger the production process in a company. Generally speaking, customer demands can be divided into two categories. The first is the normal demand which can be forecasted or estimated beforehand by a company. This kind of demand is the basis for company to conduct its production planning and scheduling. The other is the last minute order which is called rush order or demand in this paper. Company usually receives rush orders from customers after its production plan has been concluded. For these rush orders, appropriate and reasonable response is imperative as it could put strain on customer relationship and services. A good and positive response could help the company to build and retain its market share in today's highly competitive markets. The method in dealing with such orders defers from company to company. It depends on company's policy and philosophy. However, one of the underlying principle is to identify the importance and contributions of such order to company's business objectives. One of such objective is to optimize profit based on the available resources. Due to lot-size, seasonal procurement policy and production capacity balance strategy, materials available are generally more than required. There is usually an inventory cost penalty for these extra quantities, thus, to minimize the product inventory cost is a logical and reasonable consideration.

II. PROBLEM MODELING

A. Material Availability and its Inventory

Generally, the material and component quantity available is greater than required to meet the normal demands because of lot-size, seasonal procurement policy and production capacity balance strategy. In this paper, the quantity of material/finished product that is available to meet the production requirement or customer demand is called available-to-promise (ATP). ATP is bucketized weekly. A typical material availability is showed in Fig 1.



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The material inventory cost before its usage for production is,

$$CM_j = \gamma_{m_j} *(e_j - b_j)*(Q_{e_j} - Q_{b_j}) \quad (1)$$

Where, γ_{m_j} is the inventory cost coefficient per unit per time bucket for material m_j;
$j \in J$; J is the maximum number of materials required to produce the finished product;
e_j and b_j are the ending and beginning time bucket for this material subjected to inventory cost;
Q_{e_j} and Q_{b_j} are the corresponding quantities at time bucket e_j and b_j respectively.
From the inventory point of view, the sooner the quantity is consumed, the less inventory cost this material is subjected to. That is, the time bucket e_j for this material should start as early as possible.

B. Finished Product Availability and its Inventory

The ATP quantity of finished product can be used to fulfill the customer orders too. Generally, due to the constraint of material availability and production capacity, ATP chart along time bucket is showed in Fig. 2.

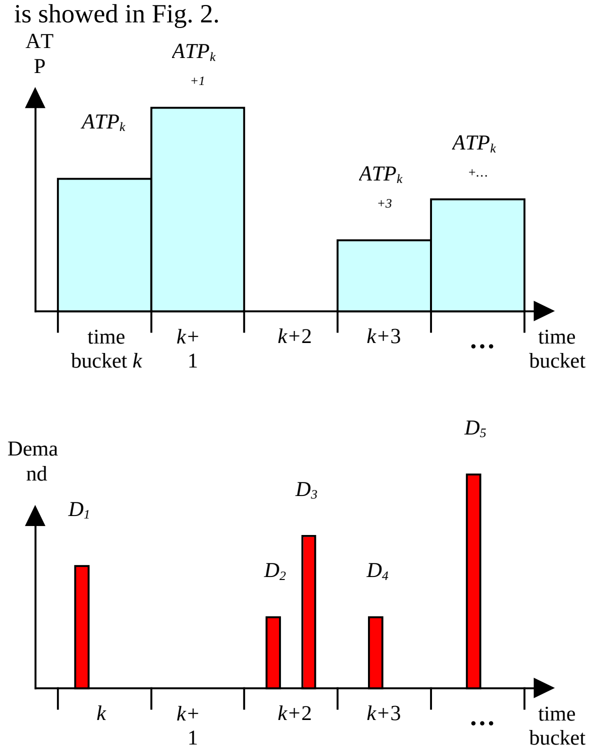

Fig.2 ATP vs. customer demands

Because of time constraint, ATP can only be used to fulfill the customer orders onwards from the time bucket when the ATP is maintained. For instance, ATP_k can be used to fulfill such demands as D_1 to D_5 in Fig. 2. But ATP_{k+1} cannot be used to fulfill demand D_1.
For a given D_i, the finished product inventory is,

$$CP_k^i = \beta *(t_i - t_k)*D_i \quad (2)$$

where, β is the inventory cost coefficient per unit

t_i is time bucket for customer demand D_i for $i \in M$;
K is the maximum number of time bucket considered;
M is the maximum number of customer demands.
The fulfillment of customer demand is actually an ATP consumption process. In this process, the product inventory cost must be considered in the circumstances of limited production capacity.

C. Overall Modeling

For simplicity, only one finished product is considered. In this scenario, the core of fulfillment of rush customer demands under limited capacity is to determine the selected customer demand set based on the ATP along time horizon.
Prerequisite: customer demands D_i, $i \in M$;
ATP quantities ATP_k, $k \in K$;
Modeling objective:

$$Min \text{ Cost} = \sum_{k=1}^{K}\sum_{i=1}^{I}(\alpha_i * CP_k^i)$$

$$= \sum_{k=1}^{K}\sum_{i=1}^{I}\alpha_i * \beta *(t_i - t_k)* D_i \quad (3)$$

where, α_i is a Boolean parameter $\forall\ i \in M$.
Subject to:
Production capacity constraint.
The constraint of limited production capacity is the main constraint incurred to the fulfillment of customer rush demands. This constraint restricts the ATP computation process and strongly influences the ATP quantities along time bucket. It will be described in detail in next section.
ATP constraint.

$$\sum_{k=1}^{K} ATP_k \geq \sum_{i=1}^{I}\alpha_i D_i \quad (4)$$

ATP constraint is a product availability constraint which represents the sum of customer demands cannot exceed the sum of ATP of a finished product.
Time constraint.
The inventory cost of finished product only incurred before finished product is consumed by customer demand.

$$t_i \geq t_k;\ \forall\, i \in M \text{ and } \forall\, k \in K$$

The Boolean variable α_i restriction.

The Boolean variable α_i is equal to 1 only if customer demand D_i can be fulfilled fully.
The problem for customer demand fulfillment is a constraint-based solution solving problem. By modeling it properly, it can be solved by means of general optimization methods such as linear programming (LP) and genetic algorithm (GA). However, due to the complicated computation process for ATP, production capacity as well as product structure, it is difficult to integrate several

What's the mathematical model for ATP and its computation? In the following sections of this paper, these issues will be elaborated on accordingly.

III. SOLUTION SEARCHING

There are two main portions involved in the solution searching process for consideration: ATP computation and ATP consumption. ATP computation is a process of calculating the ATP quantity based on material availability and production capacity. ATP consumption process is to determine the prioritized customer demands.

A. ATP Computation under Limited Capacity

In ATP computation, both material availability and production capacity needs to be considered. The ATP computation process is complex because material availability usually resides in every node of each BOM level,. In order to handle the complex issues of BOM and BOM explosion, a dynamic BOM is proposed in this paper. The dynamic BOM is a one-level BOM which is generated dynamically in the process of BOM explosion as illustrated in Fig. 3. Fig. 4 shows a typical dynamic BOM.

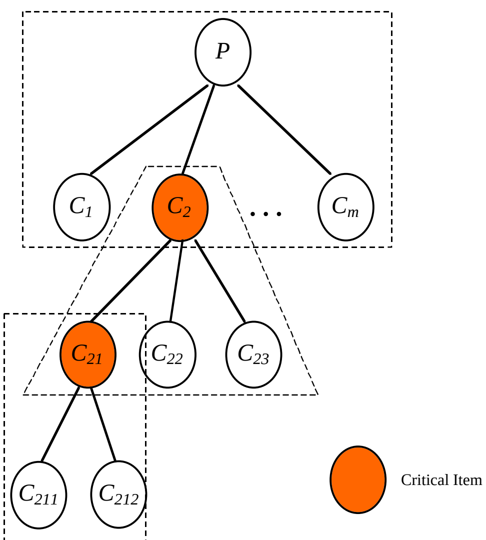

Fig. 3 The process of dynamic BOM explosion

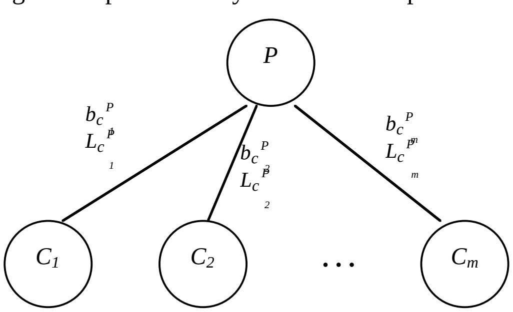

Fig. 4 A Typical Dynamic BOM

In Fig. 3, finished product P is produced by components C_1, C_2, …, C_m. $b^P_{C_n}$ and $L^P_{C_n}$, for n = 1, 2, …, m, are the quantity per BOM and determined temporarily by one of its components which is called *Critical Item*. The critical item is an item that restricts the production process at this moment. That is, it might be one with following commitment quantity,

$$Q_{commit}' = \underset{j \in m}{Min}\left(\frac{Q_{C_j}}{b^P_{C_j}}\right) \qquad (5)$$

where, Q_{C_j} is the quantity available at this time bucket for this component for $j \in m$.

However, after critical item is determined, the production capacity constraint for this production process must be further verified in order to determine the proper commitment quantity under limited production capacity. This process can be calculated as follows.

$$Q_{commit} = \begin{cases} Q_{commit}'\,; & \text{if } Q_{commit}' * \varphi \le Capacity\_avail \\ \dfrac{Capacity\_avail}{\varphi}\,; & \text{if } Q_{commit}' * \varphi > Capacity\_avail \end{cases} \qquad (6)$$

Where, Q_{commit} is the commitment quantity for this critical item under limited production capacity;

φ is the production capacity coefficient in hour per unit for this finished product;

Capacity_avail is the production capacity available for this critical item.

After critical item has been identified and the associated Q_{commit} calculated, this critical item is then replaced by its child components (if any). Then a new one-level BOM is created; a new round Q_{commit} is calculated and ATP is accumulated from Q_{commit} gradually until the critical item is the raw material. The main ATP computation process for one time bucket can be summarized as follows.

Algorithm name: ATP computation

Step 1. Computation initialize: *ATP*=0.

Step 2. Generate a dynamic BOM.

Step 3. Compute:

Q_{commit}' by formula (5);

Production capacity by formula (6);

$ATP = ATP + Q_{commit}$;

The consumed material availability by this dynamic BOM;

The consumed production capacity by this dynamic BOM

Step 4. Verify the production capacity constraint.

If *Capacity_avail* (in formula (6)) is insufficient: $Q_{commit}' * \varphi > Capacity\_avail$

Then Goto next time bucket.

Step 5. Search for critical item.

If critical item has child components, then start a new round of computation: Goto Step 2.

Otherwise, Goto next time bucket.

One of the most important considerations possible. In this way, the inventory cost for all raw materials and components can be decreased. The proposed dynamic BOM is a good method to handle the complexity of BOM, BOM explosion as well as production capacity. Because of its accumulative characteristic, the material availability residing on every middle-level of BOM and production capacity can be considered simultaneously and effectively.

B. ATP-based Fulfillment of Customer Demands

Generally speaking, there are two methods to deal with the problem of ATP-based fulfillment of customer demands: mathematical optimization and heuristic algorithm. These two methods are elaborated on as follows.

B.1 Mathematical Optimization

As discussed above, the assignment of ATP to customer demands is a constraint optimization problem. Referring to the overall model proposed in 2.3 above, a model can be built to solve the problem by the objective of minimizing the product inventory cost.

Let:

q_{ki} is the assignment quantity from ATP_k to customer demand D_i for $k = 1, 2, \ldots, K$ and $i = 1, 2, \ldots, M$.

Based on the above formula (2), the objective to minimize the inventory cost can be modeled as,

$$Min[\sum_{k=1}^{K}\sum_{i=1}^{M}\beta*(t_i - t_k)*q_{ki}] \qquad (7)$$

Subject to the following constraints:

ATP constraint:

$$ATP_k \geq \sum_{i=1}^{M} q_{ki}\ ,\ \forall k \in K \qquad (8)$$

Time constraint:

$$t_i \geq t_k\ ,\ \forall i \in M, \forall k \in K \qquad (9)$$

Assignment quantity constraint:

$$q_{ki} \geq 0\ ,\ \forall k \in K, \forall i \in M \qquad (10)$$

Commitment quantity constraint:

$$\sum_{k=1}^{K} q_{ki} = D_i * \alpha_i\ ,\ \forall i \in M \qquad (11)$$

The Boolean variable α_i restriction.

The Boolean variable α_i is equal to 1 only if customer demand D_i can be fulfilled fully for $i = 1, 2, \ldots, M$.

This problem can be solved by one of the optimization programs, for example, Simplex Method and Powell's Method. Finally, the Boolean vector $[\alpha_1, \alpha_2, \cdots, \alpha_M]$ represents the prioritized fulfillment of customer demands.

B.2 Heuristic Algorithm

In general, the result obtained by heuristic reasonable solution under a limited time and cost expenses. In Fig. 2, it is obvious that demand D_1 can not be fulfilled due to ATP shortage if D_1 is greater than or equal to ATP_k at that moment. For customer demand D_2 and D_3, the ATP before them can be accumulated for consideration along time bucket. Therefore, the problem of ATP consumption showed in Fig. 2 can be further modeled as a problem showed in Fig. 5 – to determine what's the prioritized fulfillment sequence for the customer demands $[D_1, D_2, D_3, \ldots]$ by accumulated ATP (ATP_k) for $k = 1, 2, \ldots, K$ at certain time bucket (k).

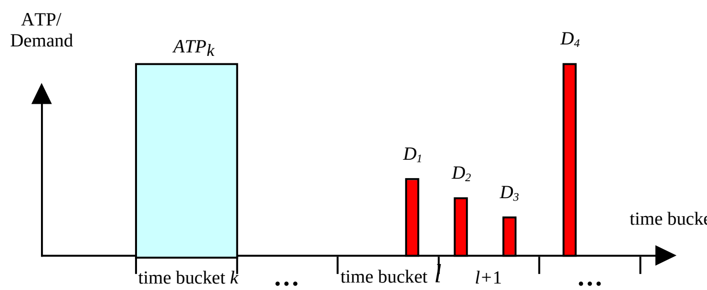

Fig. 5 The abstracted model for ATP consumption

The process of determining the prioritized fulfillment to customer demands can be described in the algorithm that follows:

Algorithm name: ATP consumption

Step 1. Computation initialize.

$i = 1$; $k = 1$; $ATP = ATP_1$

Step 2. Verify customer demand if it resides in this time bucket.

If D_i resides in the time bucket k, then Goto Step 3.

Otherwise, go into next time bucket: $k = k+1$;

Check if k is validity: If $k > K$, then Goto Step 5.

Otherwise accumulate ATP: $ATP = ATP + ATP_k$; and

Goto Step 2.

Step 3. Verify if there is enough ATP quantity at this time bucket.

If ATP is greater than or equal to D_i, then

D_i can be fully committed: $\boldsymbol{D} \Leftarrow D_i$; and

Consume ATP: $ATP = ATP - D_i$;

Step 4. Go for next customer demand: $i = i + 1$;

Check if i is validity: If $i > M$, then Goto Step 5.

Otherwise Goto Step 2.

Step 5. Output: output the customer demand sequence $\boldsymbol{D}$;

End of the algorithm.

Both methods of mathematical optimization and heuristic algorithm are all able to obtain the industry satisfied result. Comparing the mathematical optimization and heuristic algorithm, mathematical optimization method can lead to a precious result but it may spend more time and cost to get it. On the contrary, the heuristic algorithm may lead to a reasonable result based on a limited time and cost expenses. It is especially suitable for practical industry applications.

IV. CONCLUSIONS

The fulfillment of rush customer demands is an important problem faced by a lot of companies in recent competitive markets. How to respond to customer demand and inquiry rapidly and efficiently is vital for a company to retain and increase its market share. For dealing with this problem, ATP-based customer demand fulfillment is more reliable and effective because in the ATP computation process the material availability, production capability, and lead-time can be taken into consideration easily and simultaneously.

In this paper, a series of analysis and modeling with the objective to decrease the inventory cost under limited production capacity is conducted. For modeling the problem, two main issues are studied in detail: the ATP-based fulfillment ability and the prioritized fulfillment of customer demands. ATP is bucketized and calculated based material ability and production capacity, and is hence a suitable criterion to measure fulfillment ability of a company to its customer demands. In ATP computation process, the concept of dynamic BOM is proposed to handle complicated BOM and BOM explosion issues. Because dynamic BOM is generated dynamically at the process of exploding BOM one level by one level downwards, the material availability and production capacity constraint can be taken into consideration easily and efficiently. For the prioritized fulfillment from ATP to customer demands, two methods of mathematical optimization and heuristic algorithm are put forward and elaborated on in the paper. The mathematical optimization method can be modeled in mathematical formula and solved by an optimization program. It can lead to a precious solution for customer demand fulfillment based on bucketized ATP. On the contrary, the heuristic algorithm employs step-by-step reasoning algorithm to deal with ATP accumulation and its fulfillment of customer demands. It can also lead to a practical solution in terms of its limited time and cost expenses, and is therefore suitable for applications in industry.

Due to the complexities involved in the problem, there are, of course, some issues that are remained and needed to study in the future:

Mixed finished product requirements;

Case study; and

Construction of decision supporting system based on the method proposed.

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