Available Capacity Allocation Planning for Forecasting Collaboration with Uncertain Demand

Yi-Sheng Wu, Department of Industrial Engineering and Management, Yung-Ta Institute of Technology & Commerce
Juin-Han Chen, Department of Industrial Engineering and Management, Cheng Shiu University

ABSTRACT

Demand information sharing has been recognized as a key element in supply chain coordination. In the end of 1990s, according to the process model of Collaborative Planning, Forecasting and Replenishment (CPFR), numerous companies have engaged in collaborative forecasting pilots. Retailers such as Wal-mart along with manufacturers such as Procter & Gamble have getting positive benefits from CPFR projects. In spite of these successful cases, demand information sharing still suffers from several issues. First, forecasts are continuously updated and modified by the buyers when they receive new information. The degrees of uncertainty of the forecasts are increasingly for the long-term. From the supplier’s point of view, this leads to the question of how to act on the uncertain demand forecasts. Second, after the suppliers receiving the demand forecasts from buyers, how the suppliers to prioritize reserving available capacity for buyers’ demand forecasts in short supply. Therefore, in short supply, to beneficially reserve available capacity for high-margin products or high-priority buyers, this study proposes one available capacity allocation planning mechanism and applies optimal methodology in the allocation planning mechanism. In which, this research applies fuzzy mathematical programming approach to the reservation mechanism with uncertain demand that can assist suppliers to reserve manufacturing resources more satisfyingly for buyers’ demand forecasts. Reserving available capacity for buyers’ giving demand forecasts is also one reciprocal reservation mechanism that can stabilize production planning of both suppliers and buyers. Once products of highly customization from one buyer are adopted, buyers will provide future demand forecasts for the suppliers. The sharing demand information can assist suppliers to develop the more reasonable projection for future requirements and to reduce the inventory levels. Equivalently, the reserved quantities can reply to buyers to reduce the bullwhip effect in the supply chain environment.

Keywords: Available capacity, Allocation planning, Uncertain demand, Demand information sharing.

INTRODUCTION

Demand information sharing and collaborative forecasting have been recognized as the key elements in supply chain coordination. However, in spite of these successful cases, demand information sharing still suffers from several issues. The background of these issues and the purposes of this research will be described in the following paragraphs.

Research Background and Motivation

Facing increasing global supply chain environment, the competition between enterprises has transformed into the competition between supply chains. Supply chain management is defined as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that products are produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements (Simchi-levi et al., 2000). Over the last few decades, supply chain management has drawn much attention in both industrial and academic fields. In which, many studies exhibit that collaboration on demand forecasting, i.e. sharing of forecasts and joint forecasting between companies, is an essential approach to improve demand visibility and to enhance supply chain efficiency (Lee et al., 1997; Helms et al., 2000; Berratt and Oliveira, 2001). Demand information sharing has been recognized as a key element in supply chain coordination.
In the end of 1990s, according to the process model of Collaborative Planning, Forecasting and Replenishment (CPFR) that combines the intelligence of multiple trading partners in the planning and fulfillment of customer demand, numerous companies have engaged in collaborative forecasting pilots. Retailers such as Wal-mart along with manufacturers such as Procter & Gamble have getting positive benefits from CPFR projects. The benefits for buyers are increased sales, higher service levels, faster order response times, and lower product inventories, obsolescence, and deterioration; one the other hand, the benefits for sellers are increased sales, higher order fill rates, lower product inventories, faster cycle times, and reduced capacity requirements (Fliedner, 2003).

In spite of these successful cases, demand information sharing still suffers from several issues. First, forecasts are continuously updated and modified by the buyers when they receive new information. According to the CPFR model, trading partners share their plans for future events, and then an exception-based process is utilized to deal with changes or deviations from plans. However, the degrees of uncertainty of the demand forecasts are increasing for long term (see Fig. 1). From the supplier’s point of view, this leads to the question of how to act on the uncertain demand forecasts. Second, when the suppliers receiving the demand forecasts from buyers, how the suppliers to prioritize reserving available capacity for buyers’ demand forecasts in short supply. Moreover, in times of manufacturing resource shortage, when the suppliers receiving all the buyers’ quotation orders, the collaborative partners’ buyers should be given higher priority for order fulfillment. Therefore, the manufacturing resource reservation mechanism and order promising planning mechanism should be transformed to fit for the current trend of demand information sharing.

![Figure 1: Time Phases of the Collaboration (Kilger and Reuter, 2005)](image)

**Purpose of Research**

A fairly large body of literature exists on the demand information sharing and collaborative forecasting to improve supply chain performances. However, within that literature, there is a surprising lack of investigations on transforming manufacturing resource reservation mechanism and order promising planning mechanism to fit for the current trend of demand information sharing. It appears that suppliers have experienced issues on how to reserve manufacturing resource for customer sharing demand forecasts when in short supply and how to allocate manufacturing resource for all customer quotation orders that the collaborative partners’ customers should be given higher priority for order fulfillment.

Taking CPFR model as example, there are eight major collaboration tasks, that are collaboration arrangement, joint business plan, sales forecasting, order planning / forecasting, order generation, order fulfillment, exception management, and performance assessment. In the orders planning / forecasting phase, the buyers inform suppliers of future product ordering and delivery requirements. The suppliers should then respond the corresponding forecasts that the suppliers can provide. These matters derive the issue on how the suppliers to reserve manufacturing resource for customer sharing demand forecasts in short supply. Moreover, the buyers continuously update and modify forecasts when they receive new information, and the degrees of uncertainty of the demand forecasts are increasing for long term. From the supplier’s point of view, this leads to the question of how to act on the uncertain demand forecasts. In addition, in the order generation phase, the buyers convert the demand forecasts into firm orders and then the suppliers should respond the corresponding quotation orders that the suppliers can fulfill. In which, the suppliers should ponder how to allocate manufacturing resource for all customer quotation orders that the collaborative partners’ customers should be given higher priority for order fulfillment.
In light of these concerns, this study has four purposes as follows:

1. To fit the trend of demand information sharing, propose one manufacturing resource reservation planning model applying optimal methodology to assist suppliers beneficially in reserving resources for customers’ sharing demand forecasts. In which, this study applies fuzzy mathematical programming approach to the reservation planning model for the uncertain demand forecasts that can assist suppliers to reserve manufacturing resources more acceptable for buyers’ demand forecasts.

2. To give customers more reliable order promises and to enhance manufacturing resources utilization for high-margin or high-priority demand, propose one order promising planning model applying optimal methodology to assist suppliers efficiently and beneficially in allocating resources for customers’ quotation orders.

3. Take CPFR model as demonstration to exhibit the necessity of manufacturing resource reservation planning model and order promising planning model for the current trend of demand information sharing.

The major intention of this research is to enhance order fulfillment in order to build core-competence for suppliers through giving customers more reliable order promises and through promoting manufacturing resources utilization for high-margin or high-priority demand. This research is major involved in two planning problems, which are manufacturing resource reservation planning problem and order promising planning problem. For the above purposes to be achieved, this article is structured as follows. First, a review of the relative literature is in section 2. Second, the CPFR model is introduced in section 3 to indicate the two derived planning problems from collaborative forecasting. Third, the function, definition and planning model of manufacturing resource reservation planning are introduced in section 4. And finally, the role, definition, difficulties and planning model of order promising planning are described in section 5.

**LITERATURE REVIEW**

The following are the relative literature review and then indicate the distinct features of this research.

**Criticisms of Conventional Order Promising Mechanisms**

According to APICS (American Production and Inventory Control Society) dictionary (9th edition), ATP is the uncommitted portion of a company’s inventory and planned production maintained in the master schedule to support customer order promising. Kilger and Schneeweiss (2005) indicated that the assumptions of this conventional order promising mechanism, infinite capacity of manufacturers and suppliers and fixed lead-time of production and purchase, result in infeasible order promising and decreasing the delivery performance.

Moreover, this conventional approach to order promising just adapts to make-to-stock model that ATP exhibiting availability of finished goods are used to support customer order promising on first-come-first-served policy that all orders are treated the same. The order promising planning of assemble-to-order or make-to-order model is different from make-to-stock model. In make-to-stock model, the major bottleneck for demand fulfillment is the available stocks of...
finished goods. In assemble-to-order or make-to-order model (see figure 2 and table 1), the manufacturing resources such as materials and capacity after CODP should be checked and allocated for order promising (Kilger and Schneeweiss 2005). Besides, constraints derived from mass customization such as customer-recognized plants or material vendors, material compatibility, etc., should be considered when allocating these resources.

### Table 1: Major Limitations / Restrictions and ATP Granularity for Demand Fulfillment (adapted from Kilger and Schneeweiss, 2005)

<table>
<thead>
<tr>
<th>Production Model</th>
<th>Order Lead-time</th>
<th>Bottleneck / Restriction</th>
<th>ATP Granularity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTS</td>
<td>Transportation time</td>
<td>Available stocks of finished goods</td>
<td>Finished goods</td>
</tr>
<tr>
<td>ATO</td>
<td>Assembly time + Transportation time</td>
<td>Available stocks of components and capacity of the assembly process</td>
<td>Components; Assembly capacity</td>
</tr>
<tr>
<td>MTO</td>
<td>Production time + Transportation time</td>
<td>Available stocks of components and capacity of the production process</td>
<td>Components; Production capacity</td>
</tr>
</tbody>
</table>

### Order Promising from Master Production Schedule

On time delivery is usually used as key performance indicator for the quality of order promises. Reliable order quotes must be based on feasible supply plan. Ware and Fogarty (1990) presented that ATP is frequently calculated from the master scheduling process for promising delivery to customers and the accurate information of this quantity is key to customer service. Moreover, the different master scheduling methods used to promise customer orders will result in different delivery lead-time performance and percentage of promises kept (King and Benton 1988, McClelland 1988).

Utilizing experimental design approach to study the appropriate master scheduling methods in make-to-order environment, McClelland (1988) showed that using master production schedule to establish customer promise dates increases the percentage of promises kept and the master scheduling methods that can monitor capacity allocations and material requirements achieve a higher percentage of promises kept than that without considering capacity requirements or material availability.

Besides, in functional modules of advanced planning systems, master planning create a plan for the complete supply chain such as purchasing, production, distribution, etc. Kilger and Schneeweiss (2005) also pointed out that synchronization of the supply processes and order promising based on the master plan improve the on time delivery.

### Material and Capacity Allocation for Order Promising

With regard to material allocation for order promising, Bertrand et al. (2000) developed a hierarchical pseudo bill of material for efficient checking material availability and allocating materials to customer orders during customer order acceptance in assemble-to-order environment that product families often with many options and features are offered to the market. To handle the complex bill of material structure and the diverse characteristics of components, Xiong et al. (2003a) proposed a concept of dynamic bill of material to compute ATP quantity and date easily considering all the component availability. Moreover, to compute ATP in a timely and efficient manner, Xiong et al. (2003b) proposed a Web-based flexible available-to-promise computation system to help manufacturers understand their capability for fulfilling customer orders in terms of material availability in today’s e-business environment.

With regard to capacity allocation for order promising, Taylor and Plenert (1999) proposed a forward and backward procedure to identify capacity available-to-promise (CATP), the amount of unused machine capacity and slack machine time, for establishing realistic order promising dates. Based on this forward and backward procedure, Jeong et al. (2002) developed an ATP system for TFT-LCD manufacturing in global supply chain environment and an efficient heuristic for scheduling TFT LCD module assembly process for effectively using the unused capacity at shop floor level. Jung et al. (2003) proposed an optimized ATP system for make-to-order supply chain environment that calculates and allocates available capacity for giving customers delivery date promise. Besides, Guerrero (1991) studied how to allocate and
consume capacity in the final assembly schedule and master production schedule for assemble-to-order environment in order to maintain high order fill rates and consume capacity in an efficient manner. His research showed that different capacity allocation strategies such as ‘early allocation’, allocating to the most current part of capacity and move progressively to future periods as available capacity is exhausted, has moderate effect on order fill rates and capacity utilization. Recently, Lin and Chen (2005) proposed one order promising mechanism with ATP allocation planning considering material and capacity constraints after CODP to fulfil the requests from customers such as customer’s recognized materials or specifications.

**Order Promising Planning Methodology**

Pibernik (2005) indicated that advanced available-to-promise comprises of an assortment of methods and tools to enhance order promising and he proposed a theoretical framework of models and algorithms for order quantity and due date quoting. He used three characteristics, availability level, operating mode, and interaction with manufacturing resource planning, to classify order promising planning methods.

Chen et al. (2001) proposed a quantity and due date quoting ATP mechanism with mixed integer programming model that allows customized configurations and takes into account of a variety of realistic supply chain constraints, such as material compatibility, material substitution preferences, and capacity utilization. Moreover, Chen et al. (2002) used simulation experiments to investigate the sensitivity of supply chain performance to changes in certain parameters, such as batching interval size for collecting orders and customer order flexibility for product configuration. Besides, Ozdamar and Yazgac (1997) proposed a capacity driven planning system using a binary linear programming model for order due date setting in make-to-order production systems.

**Revenue Management and Seat Reservation**

The trend of segmentation and prioritization of customer demand drive many studies introducing revenue management approach for order booking in assemble-to-order or make-to-order environment. Revenue management is an order acceptance and refusal process that integrates the marketing, financial, and operations functions to maximize revenue from pre-existing capacity. Harris and Pinder (1995) indicated that many of revenue management environment characteristics are also found in assemble-to-order operations such as perishable resource, fixed capacity, high capacity change costs, demand segmentation, advance sales / bookings, stochastic demand, and historical sales data and forecasting capability.

Moreover, Tamura and Fujita (1995) adopted seat reservation concept to propose a new production planning and scheduling system, customer oriented production planning system, in which production seats are first created based on forecasted demand, and then orders received are assigned to the seats. The major advantage of their proposed system is its ability to efficiently respond to customer inquiries such as whether the required due date can be achieved. The proposed reservation planning and order promising planning mechanisms of our research introduces revenue management and seat reservation concept to reserve resources in advance for higher profit products and important customers.

**CPFR MODEL**

This section introduces CPFR model as one illustration to exhibit the necessity of manufacturing resource reservation planning model and order promising planning model for the current trend of demand information sharing.

In 2004, the organization Voluntary Inter-Industry Commerce Standards (VICS) defines CPFR as a business practice that combines the intelligence of multiple trading partners in the planning and fulfillment of customer demand. In which, CPFR links sales and marketing best practices, such as category management, to supply chain planning and execution processes to increase availability while reducing inventory, transportation and logistics cost. The following four CPFR activities and eight tasks are engaged by the sellers and buyers to improve their performance (see figure 3). Collaboration may also focus on just a subset of the above four activities such as Strategy & Planning, while the rest of the process is performed through conventional enterprise processes. These partial implementations are sometimes called “CPFR Lite.”
Strategy & Planning: Establish the ground rules for the collaborative relationship. Determine product mix and placement, and develop event plans for the period. In which, **Collaboration Arrangement** is the process of setting the business goals for the relationship, defining the scope of collaboration and assigning roles, responsibilities, checkpoints and escalation procedures. The **Joint Business Plan** then identifies the significant events that affect supply and demand in the planning period, such as promotions, inventory policy changes, store openings/closings, and product introductions.

Demand & Supply Management: Project consumer (point-of-sale) demand, as well as order and shipment requirements over the planning horizon. In which, **Sales Forecasting** projects consumer demand at the point of sales, and **Order Planning / Forecasting** determines future product ordering and delivery requirements based upon the sales forecast, inventory positions, transit lead times, and other factors.

Execution: Place orders, prepare and deliver shipments, receive and stock products on retail shelves, record sales transactions and make payments. In which, **Order Generation** transitions forecasts to firm demand. **Order Fulfillment** is the process of producing, shipping, delivering, and stocking products for consumer purchase.

Analysis: Monitor planning and execution activities for exception conditions. Aggregate results, and calculate key performance metrics. Share insights and adjust plans for continuously improved results. In which, **Exception Management** is the active monitoring of planning and operations for out-of-bounds conditions. Performance Assessment is the calculation of key metrics to evaluate the achievement of business goals, uncover trends or develop alternative strategies.

---

**Figure 3: CPFR Model and Collaboration Tasks (VICS, 2004)**

The CPFR benefits from several pilot programs are as follows (Fliedner, 2003):

1. Retailer benefits: increased sales; higher service levels; faster order response times; lower product inventories, obsolescence, and deterioration.
2. Manufacturer benefits: increased sales; higher order fill rates; lower product inventories; faster cycle times; reduced capacity requirements.
3. Shared supply chain benefits: direct material flows (reduced number of stocking points); improved forecast accuracy; lower system expenses.

Although the benefits from collaborative forecasting such as CPFR model are recognized by many researches, there is very limited study on how the suppliers to prioritize reserving available capacity for buyers’ demand forecasts in short supply and on how to allocate manufacturing resource for all customer quotation orders that the collaborative partners’ customers should be given higher priority for order fulfillment. The first issue occurs in the CPFR task of **Order Planning / Forecasting**, and the second issue occurs in the CPFR task of **Order Generation**.
MANUFACTURING RESOURCE RESERVATION PLANNING

Traditionally, suppliers adopted the first-come-first-served policy for order promising in which all buyers’ orders are treated the same without considering the margins of the products and the importance of the customers. Conventionally, in short supply, to accept orders of key customers or orders with high margins, suppliers have to break commitments that have been given to other customers. Thus, to optimize the revenue and profitability of the suppliers, and to prevent from destroying the customer relationship, manufacturing resource reservation planning mechanism can be exploited that reserves manufacturing resource prior to important customers or high-margin products based on the suppliers’ self-forecasted demand or on the buyers giving demand forecasts. Thanks to the current trend of demand information sharing and collaborative forecasting, the suppliers can obtain the buyers’ demand forecasts effortlessly.

In which, reserving available manufacturing resource for buyers’ giving demand forecasts is also one reciprocal reservation mechanism that can stabilize production planning of both suppliers and buyers. Once products of highly customization from one buyer are adopted, buyers will provide future demand forecasts for the suppliers. The sharing demand information can assist suppliers to develop the more reasonable projection for future requirements and to reduce the inventory levels. Equivalently, the reserved quantities can reply to buyers to reduce the bullwhip effect in the supply chain environment.

The manufacturing resource reservation planning mechanism is to reserve available manufacturing capacity for demand forecasts according to the margins of the products or the importance of the customers. For example, for the next six months, the available capacity of one manufacturer is 12,000 each month and the total demand forecasts from four collaborative partners exceed the available capacity (see figure 4). Then, the manufacturer can decide to reserve available capacity according to the importance of the customers, that C1 possesses the highest priority and C4 has the last priority. Figure 5 shows the result of the reservation planning.

In addition, forecasts are continuously updated and modified by the buyers when they receive new information. The degrees of uncertainty of the forecasts are increasingly for the long-term. From the supplier’s point of view, this leads to the question of how to act on the uncertain demand forecasts. This research applies fuzzy mathematical programming approach to the reservation mechanism with uncertain demand that can assist suppliers to reserve manufacturing resources more satisfyingly for buyers’ demand forecasts.

Fuzzy Mathematical Programming for Uncertain Demand

Consider the linear programming model of problem “maximize an objective function subjective to constraints” as follows where $c$ and $x$ are $n$-vectors, $b$ is an $m$-vector, and $A$ is an $m \times n$ matrix:

$$
\text{Maximize} \quad z = c^T x
$$

such that

$$
A x \leq b,
$$

$$
x \geq 0
$$
Different parts of this crisp model such as $c$, $b$, $A$ or even the constrained inequalities and objective function can be considered fuzzy. The elements of $c$, $b$ or $A$ are not crisp numbers but fuzzy numbers, the constraints can be represented by fuzzy sets rather than by crisp inequalities, and the objective function can be represented by fuzzy set or by a fuzzy function. The general fuzzy mathematical programming approach proposed by Inuiguchi and Ramik (2000) that the first phase transforms the fuzzy model to a usual mathematical model, the second phase solves the transformed mathematical model by an optimization technique, and the third phase examines the optimality and efficiency of the solution.

According to the symmetry decision-making problem that treat objective function and constraints without different proposed by Bellman and Zadeh (1970), fuzzy mathematical programming models can be classified into the following two categories, symmetrical models and nonsymmetrical models (Zimmermann 1985). In which, there are two approaches for nonsymmetrical fuzzy models: one is the determination of the fuzzy set decision; the other is the determination of a crisp optimal decision by aggregation the objective function with the constraints through appropriate transformations. The proposed planning models of these fuzzy constraints from fuzzy demand are nonsymmetrical models and this study applied the second approach to get a crisp optimal reservation decision.

Resource Reservation Planning Model

According to the description of manufacturing resource reservation planning mechanism, this mechanism is valuable under the following assumptions.

Model Assumption:

1. Supply constrained mode that the forecasted demand excess than the capability of the supply manufacturing resources.
2. The aggregation production plan for each product from production plan department is known.
3. The forecasted demand of each customer for each product is known from customers or sales department.
4. The unit profit or value of each product for each customer is known from sales department or customers.
5. Backlogging is not allowed for customer demand.
6. Customers allow the reduction of the reserved quantities. But the decrease in proportion to the insufficient volume.

This resource allocation planning problem can be modeled as a transportation problem which containing supply nodes as multiple periods of production plan and demand nodes as multiple periods of forecasted customer demand.

Index:

- $i$: customers; $i = 1, 2, ..., I$;
- $t$: periods; $t = 1, 2, ..., T$.

Parameters:

- $u_i$: the unit profit of each product from customer $i$;
- $v_i$: the unit cost of losing order for each product from customer $i$;
- $d_{it}$: the forecast amount of demand for each product in period $t$ from customer $i$;
- $q_t$: the planned production quantity (ATP) of each product in period $t$;
- $c$: the inventory carrying cost of each unit product for one period;
- $c_{it'}$: the inventory carrying cost of each unit product from period $t'$ to period $t$, where $c_{it'} = 0$ if $t'$ is larger than $t$ and $c_{it'} = c(t-t')$ if $t$ is larger than $t'$.

Decision variables:

$X_{it'}$: the allocated ATP quantity supplied from production plan in period $t'$ for forecasted demand from customer $i$ in period $t$;
- $I_t$: the inventory level at the end of the period $t$.

Objective function:

The objective is to maximize total profit and prioritize allocating resources for important customers.

Maximize $Z = \sum_{i=1}^{I} \sum_{t=1}^{T} X_{it} - \sum_{i=1}^{I} \sum_{t=1}^{T} c_{it'} X_{it'} - \sum_{t=1}^{T} c I_t - \sum_{i=1}^{I} v_i \sum_{t=1}^{T} (d_{it} - \sum_{t'=1}^{T} X_{it'})$ (1)

(Profit from fulfilled demand, minus inventory holding cost and losing order cost)
Constraints:
(a) The reserved quantity should not be more than to the required quantity from each customer. But the degrees of satisfaction with the reserved quantities are decreased as figure 2.

\[ \sum_{i=1}^{T} X_{it} \leq d_{it} \quad \forall i, t \]  

(b) Customer demand is not allowed for backlogging.

\[ X_{it} = 0 \quad \forall \quad t' > t \]  

(c) The supply amount of product should not be more than the planned production quantity (ATP).

\[ \sum_{i=1}^{T} \sum_{t=1}^{T} X_{it} \leq q_{i} \quad \forall \quad t' \]  

(d) The inventory balance constraints:

\[ I_{t} = I_{t-1} + q_{i} - \sum_{i=1}^{T} \sum_{t=1}^{T} X_{it} \quad \forall t' \]  

(e) Variables are nonnegative and integer or binary constraints.

\[ X_{it} \geq 0 \quad I_{t} \geq 0 \quad \forall i, t \]  

ORDER PROMISING PLANNING

Order promising planning mechanism is valuable under the following assumptions.

Model Assumption:
(1) The material supply calendar (time-phased available material) is known.
(2) The production schedule of WIP from previous process is known. This model treats WIP as one material that is for first process after order penetration point.
(3) Customers place orders for their requirement volume, due dates, recognized production paths and recognized material combination modules of each product.
(4) Only if the required volume from other customers are less than the reserved volume for them from reservation planning phase, the total promised quantities for one customer cannot exceed its reserved volume from reservation planning phase in the same planning period.
(5) Customer demand is not allowed for backlogging.
(6) Customers cannot allow the reduction of product supply.

To prioritize allocating time-phases material and capacity resources for fulfilling customers demand with considering derived material and capacity constraints from high customization, the mixed integer linear programming formulation is applied for solving This planning problem can be modeled as a transshipment problem which containing supply nodes as multi-stage and multi-side of production capacity and multiple material volume supplied from different vendors and demand nodes as customer quotation orders. In which, the transshipment nodes represent the allocated capacity for each production path and the allocated volume for each material combination module. Order promising planning problem is as follows. Then, the feasible quantity and due date for order promising are programming by this planning model.

Index:
- \( w \): times; \( w = 1, 2, \ldots, W \);
- \( p \): processes; \( p = 1, 2, \ldots, P \);
- \( f \): plants; \( f = 1, 2, \ldots, F \);
- \( k \): material or component types; \( k = 1, 2, \ldots, K \);
- \( l \): vendors; \( l = 1, 2, \ldots, L \);
- \( r \): production paths; \( r = 1, 2, \ldots, R \);
- \( g \): material combination modules; \( g = 1, 2, \ldots, G \).

Parameters:
- \( W(t) \): the set of times which are in the period \( t \);
\( \theta_{it} \): the indicator for representing if the total volume of quotation orders from customer \( i \) in period \( t \) are more than the reservation volume \( d_{it} B_{it} \) from phase \( l \) if \( \theta_{it} = 1 \) if total required volume are not more than the reservation volume; otherwise, \( \theta_{it} = 0 \).

\( K(p) \): the set of materials which are processing in process \( p \);

\( \gamma_{klw} \): the resource usage of material \( k \) supplied by vendor \( l \) for each finished product;

\( o_{iw} \): the amount of quotation order for each product at time \( w \) from customer \( i \);

\( \alpha_{ir} \): the indicator of customer’s recognized production path ( \( \alpha_{ir} = 1 \) if customer \( i \) prefers production path \( r \); otherwise, \( \alpha_{ir} = 0 \));

\( \beta_{ig} \): the indicator of customer’s recognized material combination module ( \( \beta_{ig} = 1 \) if customer \( i \) prefers material combination module \( g \); otherwise, \( \beta_{ig} = 0 \));

\( \delta_{rpf} \): the indicator for representing if the plant of one process is on production path \( r \) ( \( \delta_{rpf} = 1 \) if plant \( f \) of process \( p \) is on production path \( r \); otherwise, \( \delta_{rpf} = 0 \));

\( \omega_{gkl} \): the indicator for representing if the vendor of one material belong material combination module \( g \) ( \( \omega_{gkl} = 1 \) if vendor \( l \) of material \( k \) belong material combination module \( g \); otherwise, \( \omega_{gkl} = 0 \));

\( CATP_{pf} \): available capacity of plant \( f \) for process \( p \) at time \( w \);

\( MATP_{kib} \): supplying volume of material \( k \) from vendor \( l \) at time \( w \);

\( I_{kib} \): the initial inventory level of material \( k \) supplied by vendor \( l \);

\( LT_{p} \): the lead-time of process \( p \) to processing product;

\( y \): the inventory carrying cost of one unit material at one time;

\( y_{ww'} \): the inventory carrying cost of one unit material from time \( w \) to time \( w' \); where \( y_{ww'} = 0 \) if \( w \) is larger than \( w' \) and \( y_{ww'} = y(w' - w) \) if \( w' \) is larger than \( w \).

**Decision variables:**

\( B_{iw} \): the binary variable for representing if the quotation order from customer \( i \) at time \( w \) is fulfilled, where \( B_{iw} = 1 \) if the demand is fulfilled and \( B_{iw} = 0 \) otherwise;

\( I_{kib} \): the initial inventory level of material \( k \) supplied by vendor \( l \) at the end of the time \( w \);

\( F_{pfv} \): the allocated capacity at time \( w \) of plant \( f \) for process \( p \) to production path \( r \);

\( CA_{gkl} \): the throughput capability at time \( w \) of production path \( r \);

\( A_{kibgwl} \): the allocated material at time \( w \) of material \( k \) supplied by vendor \( l \) for material combination module \( g \) outputting at time \( w' \);

\( GA_{g} \): the throughput availability at time \( w \) of material combination module \( g \);

\( P_{pwi} \): the allocated throughput capacity of production path \( r \) at time \( w \) for fulfilling quotation order of customer \( i \) at time \( w' \);

\( R_{gfw} \): the allocated throughput volume of material combination module \( g \) at time \( w \) for fulfilling quotation order of customer \( i \) at time \( w' \).

**Objective function:**

The objective is to maximize total profit and prioritize allocating resources for orders those possess reservation volume in reservation planning phase.

\[
\text{Maximize} \quad Z = \sum_{i} \sum_{t} \sum_{w} o_{iw} B_{iw} - \left( \sum_{k} \sum_{l} \sum_{w} I_{kib} + \sum_{w} \sum_{w'} y_{ww'} \sum_{k} \sum_{l} \sum_{g} A_{kibgwl} \right) \left( \sum_{w} \sum_{w'} y_{ww'} \sum_{k} \sum_{l} \sum_{g} P_{pwi} \sum_{k} \sum_{l} \sum_{g} \omega_{gkl} F_{gkl} \right) \sum_{i} \sum_{t} \sum_{w} \theta_{it} \sum_{weW(t)} (1 - B_{iw}) \]

(Profit from fulfilled orders, minus inventory holding cost and penalty cost of breaking the contract from reservation planning phase)

**Constraints:**

Constraints (a)-(c) represent the allocated capacity for production paths cannot be more than the available capacity.

\( (a) \quad F_{pfvw} \leq \delta_{rpf} CATP_{pfw} \quad \forall p,f,r,w \)
(b) \( \sum_{r} F_{pfrw} \leq CATP_{pfrw} \quad \forall p, f, w \) (9)

c (c) \( \sum_{f} F_{pfr(w - \sum_{r=p} LT_{r})} = CA_{rw} \quad \forall p, r, w \) (10)

Constraints (d)-(f) represent the allocated material for material combination modules cannot be more than the available material. Constraint (g) represents backlogging is not allowed. Constraint (h) represents inventory balance.

(d) \( Ak_{lw}w' \leq o_{gkl}(MATP_{lw} + I_{lw-1}) \quad \forall k, l, w, g, w' \) (11)
(e) \( \sum_{g} Ak_{lw}w' \leq (MATP_{lw} + I_{lw-1}) \quad \forall k, l, w \) (12)

(f) \( \sum_{l w} Ak_{lw}w' = GA_{gw} \quad \forall k, g, w' \) (13)

(g) \( Ak_{lw}w' = 0 \quad \forall k \in K(p), l, g, w + \sum_{p=p} LT_{r} > w' \) (14)

(h) \( I_{lw} = I_{lw-1} + MATP_{lw} - \sum_{g} Ak_{lw}w' \quad \forall k, l, w \) (15)

Constraints (i)-(k) represent the allocated production path capacity for customer orders should be customer’s recognized production path and cannot be more than the available capacity and should be equal to the customer required volume. Constraint (l) represents backlogging is not allowed.

(i) \( Pr_{wvw} \leq o_{it} CA_{rw} \quad \forall r, w, i, w' \) (16)
(j) \( \sum_{r w} Pr_{wvw} \leq CA_{rw} \quad \forall r, w' \) (17)

(k) \( \sum_{r w} Pr_{wvw} = B_{iw} o_{vw} \quad \forall i, w' \) (18)

(l) \( Pr_{wvw} = 0 \quad \forall w > w' \) (19)

Constraints (m)-(o) represent the allocated material combination modules for customer orders should be customer’s recognized material combination module and cannot be more than the available module volume and should be equal to the customer required volume. Constraint (p) represents backlogging is not allowed.

(m) \( R_{gwvw} \leq \beta_{ig} GA_{gw} \quad \forall g, w, i, w' \) (20)

(n) \( \sum_{i w} R_{gwvw} \leq GA_{gw} \quad \forall g, w \) (21)

(o) \( \sum_{g w} R_{gwvw} = B_{iw} o_{vw} \quad \forall i, w' \) (22)

(p) \( R_{gwvw} = 0 \quad \forall w > w' \) (23)

Constraint (q) represents the cumulative allocated production path capacity until time \( w \) cannot be more than the cumulative allocated material combination modules for customer orders because of the perishable of capacity.

(q) \( \sum_{w=1}^{w} \sum_{g} R_{gwvw} \leq \sum_{w=1}^{w} \sum_{g} R_{gwvw} \quad \forall w, i, w' \) (24)

Constraint (r) represents the total promised volume for one customer cannot exceed its AATP from phase I in the same planning period only if the required volume from other customers are less than the reserved volume AATP for them from phase I. Constraint (s) represents variables are nonnegative and integer or binary.

(r) \( \sum_{w W(t)} B_{iw} o_{vw} \leq d_{it} B_{it} + \sum_{i} \theta_{it} \left( d_{it} B_{it} - \sum_{w W(t)} o_{w} \right) \quad \forall i, t \) (25)

(s) \( B_{iw}, I_{lw}, F_{pfrw}, CA_{rw}, Ak_{lw}w', GA_{gw}, Pr_{wvw}, and R_{gwvw} \geq 0 \) (26)

\( B_{iw} \) (binary; \( I_{lw}, F_{pfrw}, CA_{rw}, Ak_{lw}w', GA_{gw}, Pr_{wvw}, and R_{gwvw} \) integer)
REFERENCES


Xiong MH, Tor SB, Khoo LP (2003b) WebATP: a Web-based flexible available-to-promise computation system. Production Planning & Control 14(7): 662-672