An Order Planning and Scheduling Framework in MTO Environment

Dechang Sun\(^1,2,3\), Haibo Shi\(^1,2\) and Chang Liu\(^1,3\)

1. Shenyang Institute of Automation, Chinese Academy of Science, Liaoning, Shenyang, China
2. Graduate School of the Chinese Academy of Science, Beijing, China
3. a. sundechang@sia.cn; b. hbshi@sia.cn; c. changl@sia.cn

Abstract—with the increasing competition, more and more manufacturers change their business policy, from MTS to To-Order (ATO), MTO, ETO, even One-of-a-Kind. All of these changes require the production system to be suitable. In light of the order process cycle model, we focused on the manufacturing process, and we presented a planning and scheduling framework for orders. Order planning promotes the controlling of inventory level. Order scheduling promotes the WIP controlling and the production compatibility. Case study in a bicycle firm indicate that the framework is valid.

Keywords—planning; scheduling; MTO; job shop; flow shop

I. INTRODUCTION

For addressing the increasing market competition, manufacturing and supply chain systems have been changed from the traditional mass production to the mass customization, even some companies adopt make-to-order (MTO) strategy to response to market demand. Consequently research in production planning and control has been transformed traditional centralized approaches to hierarchical approaches. Hierarchical approaches distribute every decision capacities in the autonomous entities which promote manufacturing planning and scheduling, and they can adjust the planning and scheduling according to actual condition. Furthermore, in the complicated manufacturing environments, it is very difficult to handle the manufacturing planning, scheduling and control problems using integrated models which is too large to obtain optimal solutions, and in practice, material planning, capacity planning, job scheduling and control require different techniques and algorithms to solve.

In the MTO companies, production process is driven by the customers’ orders. Firstly, the functional departments of the firm check the order and decide to reject or accept it. Once the order is accepted, engineering department design the item of the order, then planning division arrange the material purchasing, parts manufacturing, and so on. Finally, workshop completed the final assembly. In order to respond to the customer’s order quickly, firms usually hold the general parts inventory and purchase or manufacture the customized parts according to the order.

The production process is not always smoothly along with the planning and scheduling, order control is necessary. We must monitor the manufacturing progress, track the products position, record the abnormal events and coordinate relevant department to solve all the troubles.

The remainder of this paper is organized as follows. Section 2 reviews the literatures about Production planning, scheduling and controlling problems in MTO environment, our subsequently discusses based on these researches. Section 3 proposes an order planning, scheduling and control architecture, and discuss in detail. Section 4 uses a case to illustrate the applicability of the architecture in a bicycle company which demonstrates the whole process of the order throughout the enterprise. Section 5 conclude this paper, and point out the further researches.

II. LITERATURE REVIEW

Defined by [1], order planning and scheduling is an optimization problem that jobs are allocated to resource over time within a range of availability. But, planning functions have longer time horizon than scheduling. Sometimes, the applied fields are different, planning is face to factory and scheduling is face to shop floor. Control functions make up the gap between implementation and scheduling guarantee the performance of execute system. So this hierarchical characteristic is inherent in manufacturing planning, scheduling and control system.

According to the pattern of fulfillment customer’s demand, the manufacturing’s strategies are divided into make-to-stock (MTS) and non-MTS [2] [3] [4]. In MTS environment, large quantity of standard products are produced and stocked, which satisfied customers’ need. In non-MTS environment, firms don’t store the finished goods, and they design, configure, or assembly the products according to the customers’ requirements. Non-MTS is a general concept; it can be classified in detail. In light of the order penetration point, non-MTS divided into Assembly-To-Order (ATO), MTO, and Engineer-To-Oder (ETO) [5]. About others taxonomy of non-MTS, for example, Design-To-Order (DTO), Make-TO-Print (MTP), ETO, MTO [4], Configure-To-Order (CTO) [6], Finished-To-Order (FTO) [7], Build-To-Order [8]. Different manufacturing strategies mentioned above can be described based on volume and variety in Figure 1.
In MTO companies, all production activities are carried out around the customers’ orders. The manufacturing planning, scheduling and control functions can be divided into five stages along with the order processing cycle, detail described as following:

- **Customer Enquiry stage.** Customer provides invitation for a particular product, requiring the determination of price, quantity and due date.
- **Design & Engineering Stage.** Entering detail engineering phase if the orders are accepted, this determining the technical feasibility and manufacturability. For ETO companies, this stage is very important.
- **Order Entry Stage:** where the confirmed order is planned and due date is arranged. Including material requirements, purchasing, parts manufacturing, and shop floor routing.
- **Job Release stage:** the production system decides the orders when and where produced if the material and capacity are available. The decision would affect the workload and works-in-process (WIP).
- **Shop Floor Stage:** this stage can be divided into scheduling and controlling, the detail job scheduling will be given using Gantt chart. The production control is essential to monitor the progress to guarantee the due date.

Reference the delivery date model of Kingsman [8], an extend model illustrate the five stages in Figure 2.

Reference the delivery date model of Kingsman [8], a extend model illustrate the five stages in Figure 2.

**III. ORDER PLANNING AND SCHEDULING FRAMEWORK**

This paper is focus on the later three stages of order process cycle (see Figure 2). At the beginning of order entry, the order status is confirmed, that means the quantity, due date, priority is determined, and the Bill of material (BOM) and routes are specified. Then, the following tasks are making material planning, allocating equipment resource for the order. In the whole framework, different stages are restrained in mutual. The input parameters of the latter stage are the output of former. Figure 3 illustrates the framework.

- **Order Planning.** It is the staring of the manufacturing lead time. The objective is to control the inventory level and optimize the material preparation lead time. The inputs mainly include confirmed sales order, parts and components inventory, products BOM. Using MRP logic, the outputs are finished products, parts.
and components aggregate requirement, inventory reservation and purchasing planning.

- Order Scheduling. According to the outputs of order planning, the requirements of inner manufacturing parts are transformed into production order, and the requirements of outer purchasing are transformed into purchasing order. If the materials are available, the production orders are chosen to release to shop floor using some rules. The objective is to balance the workload and reduce WIP. The shop floor scheduling is to sequence the jobs for workstation and assembly lines and reduce the queuing times in all workstations. The objective is to reach the due date and improve the utilization rate of the facilities.

A. Order Planning

Once, the sales orders were confirmed, planning system work out the requirement quantity, date information of all kind of material using MRP logic. The outputs include inventory reservation, purchasing planning, aggregate parts production planning, aggregate finished products planning.

1) Inventory reservation

Within the available quantity \( V_m \), the allocated amount for every order is so-called inventory reservation.

\[
R_e = \min (q_i \times q_{mP}, V_m) \quad (i \in I, m \in M.G)
\]

\[
\sum_{i=1}^{I} R_e \leq V_m
\]  

(1)

2) Procurement planning

Amount of purchasing general part \( m \):

\[
AM.O.G_m = \sum_{i=1}^{I} q_i \times q_{mP} - V_m \quad (i \in I, m \in M.O.G)
\]

Amount of purchasing customized part \( m \) for order \( i \):

\[
AM.O.C_m = q_i \times q_{mP} \quad (i \in I, m \in M.O.C)
\]

(3)

The receipt date of general part \( m \) purchasing order (PODG\( m \)):

\[
PODG_m = \min \left( DD_i - SFTT_i - LT_m \right) \quad (i \in I, m \in M.O.G)
\]

(4)

The receipt date of customized part \( m \) purchasing order m (PODC\( m \)):

\[
PODC_m = DD_i - SFTT_i - LT_m \quad (i \in I, m \in M.O.C)
\]

(5)

3) Aggregate parts manufacturing planning

The amount of self-made general part \( m \):

\[
AM.S.G_m = q_i \times q_{mP} - V_m \quad (i \in I, m \in M.S.G)
\]

(6)

The amounts of self-made customized part \( m \) for order \( i \):

\[
AM.S.C_m = q_i \times q_{mP} \quad (i \in I, m \in M.S.C)
\]

(7)

Release time of general part \( m \):

\[
GRT_m = \min \left( DD_i - ALT_i - LT_m \right) \quad (i \in I, m \in M.S.G)
\]

(8)

Due date of general part \( m \):

\[
GDD_m = \min \left( DD_i - ALT_i \right) \quad (i \in I, m \in M.S.G)
\]

(9)

Release time of customized part \( m \) for order \( i \):

\[
CRT_m = DD_i - ALT_i - LT_m \quad (i \in I, m \in M.S.C)
\]

(10)
Due date of customized part m for order i:
\[\text{CDD}_{im} = \text{DD}_i - \text{ALT}_{pi} \quad (i \in I, m \in \text{M.S.C}) \cdot \] (11)

4) Aggregate finished products assembly planning
The amount of production:
\[\text{AP} = \sum_{i=1}^{I} q_i / \text{batch size} \cdot \] (12)

Start time of order i:
\[\text{STO}_i = \text{DD}_i - \text{ALT}_{pi} \quad (i \in I) \cdot \] (13)

B. Order Scheduling
1) Job release
Job release is working under the constraints of order planning; these constraints include delivery date, material available, and the order’s priority. Job release mechanism determines amount of work-in-process, workload of workstation and shop floor performance.

Firstly, the capacity of each order production the planning period should be computed.
\[\text{CP}_i = \sum_{t=1}^{T} \sum_{p=1}^{P} C_{np} \quad (i \in I, p \in P) \cdot \] (14)

Secondly, the latest released date (LRD) of each order should be computed.
\[\text{LRD}_i = \text{DD}_i - \text{batch size} / \text{CP}_i - \text{MLT}_i \quad (i \in I) \cdot \] (15)

Finally, orders are sorted by LRD ascending. The orders within capacity of planning period were selected. If the LRD is same, the orders having higher priority should be arranged early.

2) Job Scheduling
In the MTO environment, shop floor scheduling is a multi-objective problem, including meeting due date, promoting efficiency of machines, reducing the WIP and cutting the order production cycle. Shop floor scheduling problem can be described as three domains module: a) Job shop

a) Job shop
In the job shop, many machines are set up. The manufacturing jobs are the self-made parts. The objective is to meet the assembly time. The job shop scheduling model described as follows:
Job set: production orders of the self-made parts, the order quantity were indicated in (6), (7), the order release time and due time were indicated in (8), (9), (10), (11).
Machine environment: Jc, there are C machines.
Objective: meeting the requirement of final goods assembly. This problem using three domains module is described as:
\[\text{Jc} \parallel p_{r_{j}} \min \{\text{DF}_{j}, C_j\}, 0 \cdot \] (16)

b) Flow shop
Flow shop can be divided into flexible flow shop and permutation flow shop. The former consists of a number of stages in series with machines in parallel at each stage; a job has to be processed at each stage on only one of the machines. The later only has one machine at each stage, and the sequence of jobs is not allowed to be changed between machines till the end. Figure 4 illustrate the difference between flexible flow shop and permutation flow shop.

![Figure 4. Flexible and permutation flow shop](image)

The flow shop scheduling model described as follows:
Job set: the results of formula (12), (13).
Machine environment: for flexible flow shop, FFS, there are n stages and m machines in each stage.
Objective: meeting the due date of orders. The problem using three domain module is described as:
\[\text{FFS} | p_{r_{j}} T_{j} \min \{\text{DD}_{j}, C_{j}\}, 0 \cdot \] (17)

For solving the scheduling problem, many rules and algorithms have been developed. The rules include FCFS, SPT, LTP, ERD, and EDD and so on. The algorithms include branch and bound, shifting bottleneck, constraint programming, genetic algorithms, simulate method, etc.

In this section we present the orient to sales order planning and scheduling framework, and analyze the relationship between the main factors. The order planning used MRP logic. For the general parts, stock was consumed if the general parts have available inventory, or it were manufactured. For the customized part, it was purchased or manufactured in the light of the orders. Thus the inventory level is controlled. Order scheduling is executed separately in parts manufacturing and products assembly, improving the compatibility of production progress and controlled the WIP.

IV. CASE STUDY
We researched a bicycle manufacturer, which provides three kinds of goods (Ladies, Men, Kids) for customers, and the goods have two options, color (Red, Blue, and Sliver) and tyre (General, Mountain). The production system consists of two shop floors, one job shop that produces the parts and one flow shop that assembly final product. The job shop operations include cutting (C, 30s),
shaping (S, 30s), welding (W, 6Min), and painting (P, 1h). The products BOM structure is indicated in figure 5. The shop floor environment information is listed in table 1. The sales order information is listed in table 2. The material information and routes are listed in table 3. Using the order process framework, table 4 lists the order planning results including the inventory reservation for every general part, the purchasing information of outsourcing parts, the manufacturing information of self-made parts, and products assembly planning. The figures 6, 7, 8 indicate the rough planning, detailed job shop scheduling and flow shop scheduling.

**Figure 5. Bicycle BOM Structure**

<table>
<thead>
<tr>
<th>W.C.</th>
<th>Amount</th>
<th>Remark</th>
<th>A.L.</th>
<th>Remark</th>
</tr>
</thead>
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<tr>
<td>Cutter</td>
<td>2</td>
<td>Line A</td>
<td>Ladies/Men/Kids</td>
<td></td>
</tr>
<tr>
<td>Shaping</td>
<td>2</td>
<td>Line B</td>
<td>Ladies/Men/Kids</td>
<td></td>
</tr>
<tr>
<td>Welder</td>
<td>3</td>
<td>Line C</td>
<td>Kids</td>
<td></td>
</tr>
<tr>
<td>Paint room</td>
<td>1</td>
<td>80 pieces/batch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6. Aggregate Planning**

<table>
<thead>
<tr>
<th>No.</th>
<th>Prt</th>
<th>Qn</th>
<th>Pr</th>
<th>DD</th>
<th>Color</th>
<th>Tyre</th>
</tr>
</thead>
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<td>SD1101</td>
<td>LB01</td>
<td>500</td>
<td>1</td>
<td>2010.4.26</td>
<td>Red</td>
<td>General</td>
</tr>
<tr>
<td>SD1102</td>
<td>MB01</td>
<td>300</td>
<td>2</td>
<td>2010.4.20</td>
<td>Silver</td>
<td>General</td>
</tr>
<tr>
<td>SD1103</td>
<td>KB01</td>
<td>600</td>
<td>3</td>
<td>2010.4.30</td>
<td>Blue</td>
<td>General</td>
</tr>
<tr>
<td>SD1104</td>
<td>LB01</td>
<td>100</td>
<td>1</td>
<td>2010.4.26</td>
<td>Silver</td>
<td>Mountain</td>
</tr>
<tr>
<td>SD1105</td>
<td>MB01</td>
<td>200</td>
<td>2</td>
<td>2010.4.20</td>
<td>Blue</td>
<td>Mountain</td>
</tr>
<tr>
<td>SD1106</td>
<td>KB01</td>
<td>300</td>
<td>3</td>
<td>2010.4.30</td>
<td>Red</td>
<td>Mountain</td>
</tr>
</tbody>
</table>

**Figure 7. Job shop scheduling**

**Figure 8. Assembly scheduling**

V. CONCLUSION

Under the MTO environment, all the operational activities of the enterprise are focused on the orders. The core stage is from acceptance to delivery involving the main enterprise resource. In this paper, we present a planning and scheduling framework orient to sales order. This viewpoint derives from the order life cycle in the firms, especially the stage of the order throughout the manufacturing system. Inventory well controlled using material planning in light of order strictly, WIP well controlled by order scheduling. In this way, the order delivery is reliable. The case study proved the framework is valid. The further research in this field is order promising to provide more reliable amount and delivery date to customer in upstream, and order control to enable the production process more stable and efficient, to ensure the order delivery on time in downstream.

ACKNOWLEDGMENT

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REFERENCES


**TABLE 3. The material and routes information**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Type</th>
<th>Shop</th>
<th>Routes</th>
<th>Inventory</th>
<th>Option</th>
<th>Lead Time</th>
<th>Batch size</th>
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</thead>
<tbody>
<tr>
<td>HL-01</td>
<td>handlebar</td>
<td>Self-made</td>
<td>Job</td>
<td>C-S-P</td>
<td>--</td>
<td>Customized</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>HL-02</td>
<td>front fork</td>
<td>Self-made</td>
<td>Job</td>
<td>C-S-W-P</td>
<td>--</td>
<td>Customized</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>HL-03</td>
<td>brake</td>
<td>Outsourcing</td>
<td>--</td>
<td>--</td>
<td>550</td>
<td>General</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>FR-01</td>
<td>frame</td>
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<td>Job</td>
<td>C-S-W-P</td>
<td>--</td>
<td>Customized</td>
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<td>20</td>
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<tr>
<td>FR-02</td>
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<td>Outsourcing</td>
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<td>280</td>
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<td>500</td>
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<td>C</td>
<td>560</td>
<td>General</td>
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<td>100</td>
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<td>FR-04</td>
<td>after frame</td>
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<td>--</td>
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<td>chain</td>
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<td>--</td>
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<td>General</td>
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<tr>
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<td>Self-made</td>
<td>Job</td>
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<td>Customized</td>
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<td>--</td>
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<td>General</td>
<td>2</td>
<td>500</td>
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<td>--</td>
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<td>General</td>
<td>2</td>
<td>500</td>
</tr>
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<td>500</td>
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<td>--</td>
<td>--</td>
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<td>General</td>
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**TABLE 4. The Order Planning results**

<table>
<thead>
<tr>
<th>Material</th>
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<th>Products</th>
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<td>2010.4.28</td>
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<td>15002010.4.02</td>
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<td>galvanized plate</td>
<td>400(SD1105)600(SD1101)</td>
<td>3000</td>
<td></td>
</tr>
</tbody>
</table>