Performance Evaluation of Reserved Capacity for Due Date Promising

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Abstract

In many make-to-order production systems customers ask due date confirmed and kept. Unexpected urgent orders from valuable customers often requires short lead times, which causes existing orders in the production schedule to be delayed so that their confirmed due dates cannot be met. This imposes significant uncertainty on the production schedule in a supply chain. In this paper, we propose a new concept of capacity reservation as a viable tool for due date promising and suggest its operational alternatives. Simulation results show that the reserved capacity scheme appears to outperform simple FCFS scheduling policy in terms of the number of valuable urgent orders accepted and total profit attained.

Keywords: Reserved capacity; Due date promising; Scheduling; Order acceptance; Make-to-order; Simulation

1. Introduction

In the make-to-order (MTO) based manufacturing environment, customers usually place orders with fixed due dates. Due dates tend to be getting shorter these days mainly due to upstream uncertainties in volatile market demand. It is pointed out that prospective customers appreciate short lead times [2]. Thus MTO firms that can promise and deliver short lead times are likely to win more orders, and may earn higher profits than their competitors [10]. Due date setting and promising, however, is a difficult task and requires efficient capacity and lead time management [11]. Available-to-promise (ATP) logic is widely used to confirm delivery dates by examining all finished and in-process goods [3]. In the MTO based manufacturing environment, however, suppliers usually have few standard products and volatile difficult-to-predict demands on a variety of end items. This makes it very hard to confirm due dates for incoming work orders solely by available inventory along with ATP logic. Especially when orders have short lead times and production facilities are highly congested, decisions on whether or not to accept an order becomes very important in the context of due date promising for existing and incoming orders.

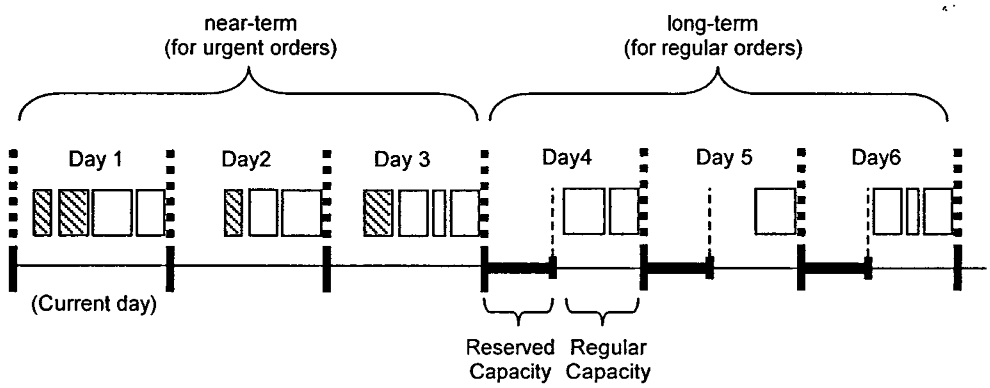
Researches on the due dates can be classified into two categories: order acceptance [8, 9, 12] and shop floor scheduling [1, 4, 5, 6, 7]. However, little research has been focusing on the fact that many suppliers have their own group of important customers who are significantly distinguished from other customers in terms of sales volume and/or strategic value. Those important customers usually place orders with very short lead times. Therefore, the objective of the suppliers is to establish a well-defined order receiving and scheduling policy which can both confirm the due dates of all accepted orders and maintain a room to accept urgent orders with short lead times from important customers.

We propose a new order acceptance and scheduling scheme, called the *reserved capacity* policy, which can effectively accept some portion of urgent orders while meeting the due dates of all accepted orders.

2. Reserved Capacity Scheme

As we propose a new concept, the production system we consider has been kept as simple as possible. We address a simple case of single production line that runs continuously for 24 hours a day; and orders arrive at any time over 24 hours. An example is multi-item continuous production process in a typical petrochemical plant. We consider situations where demand exceeds short-run production capacity from time to time so that incoming orders are usually conflicted with existing work orders in the production schedule. Otherwise due dates are of no concern.

For the convenience of our discussion, we define an *urgent order* as one whose due date is within 3 days from its arrival. All orders whose due dates are longer than 3 days are called *regular orders.* Daily production capacity is divided into two separate time segments, as shown in Figure 1. The term *reserved capacity* is defined as a certain portion of daily capacity reserved for urgent orders. (We assume that urgent orders from unimportant customers are ignored.) The remaining portion of daily capacity is called *regular capacity.* Note that reserved and regular capacity do not designate specific hours of a day, but only the portions such as 30% vs. 70% of the daily capacity. According to our scheme, regular orders are not assigned to the reserved capacity, but only to the regular capacity. Figure 1 shows an example of a six-days schedule in which urgent (shaded) and regular (white) orders are assigned to the reserved (thick-lined) and regular (thin-lined) capacity, respectively. Note that no capacity is reserved in days 1 through 3.



<Figure 1> An example of a six-day schedule using the reserved capacity concept

We define that the due date of an order is met if its production is completed by the end (24 o'clock) of the due date. An order is accepted if its due date can be met; otherwise the order is rejected. Day 1 is the current day. The reserved capacity is maintained on a daily basis. We assume the followings: 1) Each customer order comes with a fixed due date which is a hard constraint; if we cannot meet one we reject the order. 2) An urgent order has a due date of day 1 (current day), day 2, or day 3; and regular orders have due dates of day 4 through day 6. No orders with due dates after day 6 are considered. 3) Urgent orders have twice as large marginal profit as regular orders; and setup time between two consecutive jobs are ignored (or considered in the processing time). 4) Production lot size equals to order size. 5) Lot splitting for scheduling convenience is not allowed.

Let α denote the portion of the predetermined reserved capacity in a day (e.g. 30%); and let s_{kj} and r_{kj} denote the size (in units of time) of the j-th urgent and regular orders scheduled on day k, respectively. Then, S_k and R_k, the remaining reserved and regular capacity of day k, respectively, are defined as in equations (1) and (2). We also define the remaining capacity of day k, denoted as DR_k, as in (3); and the cumulative remaining capacity from day D down to day 1, denoted as CR_D, as in (4), respectively.

$$S_k = \alpha \times 24\text{ hours} - \sum_j s_{kj}, \quad \text{for } k = 1, 2, 3, \tag{1}$$

$$R_k = (1-\alpha) \times 24\text{ hours} - \sum_j r_{kj}, \quad \text{for } k = 4, 5, 6, \tag{2}$$

$$DR_k = S_k + R_k, \quad \text{for } k = 1, \cdots, D, \tag{3}$$

$$CR_D = \sum_{k=1}^{D} (S_k + R_k). \tag{4}$$

When receiving an order, a response must be given to the customer as to whether the due date can be met. To answer this, we present the following order acceptance rule. Recall that we assume the regular orders arrive with due dates of days 4 through 6. Consider an arriving regular order with processing time t^* whose due date is D ($1 \le D \le 6$). The following is the pseudo-code for the order acceptance rule:

```
For regular orders (4≤D≤6)
        for k = D down to 4
                if(R_k ≥ t*) then
                        Place the order at the end of day k. Return(update).
                end_if
        Reject the arriving order; stop
For urgent orders (1≤D≤3)
        for k = D down to 1
                if(DR_k ≥ t*) then
                        Place the order at the end of day k. Return(update).
                end_if
        if(CR_D ≥ t*) then
                Place the order at the end of day k. Return(update).
        else reject the arriving order, stop.

        function(update)
                Slide all orders already scheduled in day k to the left by t*.
                Update S_k, R_k, DR_k, and CR_D, stop.
        end_function
```

After finishing the last job scheduled on a certain day, we slide the first job scheduled on the next day to "now", while the second job and thereafter remain not shifted. If no gap exists between the last job on the current and the first job on the following, then no sliding occurs. The reason we slide next available job is that we prefer to leave rooms unscheduled for possible arrival of urgent order with very short lead times.

3. Simulation Study

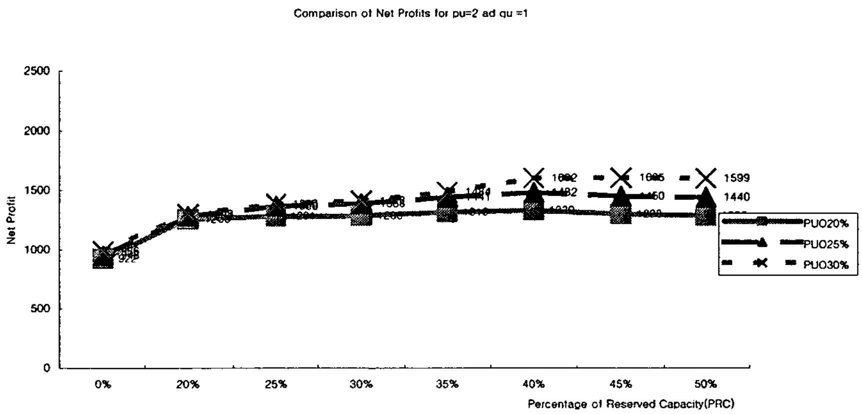
As a pilot study, we will simply compare the performance of the reserved capacity scheme with the simple First-Come First-Served (FCFS) rule. As a baseline, FCFS policy does not reserve any capacity for urgent orders, nor distinguish urgent orders from regular orders. All orders are simply assigned to the schedule in the order of their arrival. Orders with long-term due dates are scheduled by searching the schedule backwards from D down to day 1 to find the first available time slot.

We use Arena 3.5 for the discrete event simulation of the proposed system. Recall that once an order is accepted, it must not be delayed. We examine the cases where the average portion of urgent orders (PUO) is 20%, 25%, and 30% of the total number of orders; and the portion of reserved capacity (PRC) is 20% to 50% with the increment of 5% of daily capacity (i.e., 24 hours). The outputs of the simulation contain the net profit and the ratio of accepted urgent and regular orders.

We use the following parameter values; interarrival times of orders follow an exponential distribution with mean of three hours; processing time of orders follow uniform distribution between four and six hours. Due dates of urgent orders are distributed as 10%, 30%, and 60% for day 1, 2, and 3, respectively; while due dates of regular orders are evenly distributed for day 4, 5, and 6.

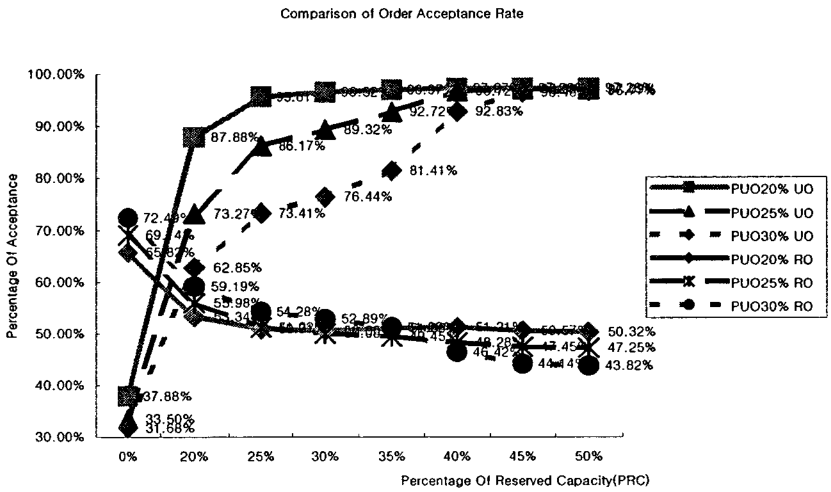
The net profit is defined as the total profit from the processed orders less the opportunity loss from the rejected orders. Urgent orders usually yield more profit than regular orders [10]. We assume that the profit and the loss from a job are independent of its processing time since the processing time is assumed to vary only between 4 to 6 hours in the experiment. Let p_u (p_r) denote the profit obtained when an urgent (regular) order is processed. Similarly, let q_u (q_r) denote the loss when an urgent (regular) order is lost due to lack of sufficient capacity available before its due date. For simplicity, we assume that $p_r = q_r = 1$; and consider the cases where p_u and q_u vary between 1 and 3. We regard these numbers as reasonable ones in practice. Simulation is conducted for 30 replications, each of which runs for 10,000 hours with initial 168 hours truncated.

Figure 2 shows the result of net profits attained by using the reserved capacity scheme. The percentage of reserved capacity (PRC) varies from 0% through 50% with $p_u = 2$, $q_u = 1$. The case where PRC=0% corresponds to the FCFS policy. The case where PRC=10% is not considered in the simulation because 10% of the reserved capacity, which amounts to 2.4 hours a day, is too small to accept an urgent order of a mean of five hours. The three lines in Figure 2 correspond to the net profits when the percent of urgent orders (PUO) is 20%, 25%, and 30% of the number of orders, respectively.



<Figure 2> Comparison of Net Profits when $p_u = 2$ and $q_u = 1$

In Figure 2, the net profit increases as PRC and PUO increases. That is, the more the urgent orders arrive, the larger the capacity should be reserved for the urgent orders. It is observed, however, that if excessive portion of the capacity is reserved for urgent orders, then the net profit decreases since more regular orders will be rejected. Therefore, a desirable level of reserved capacity is observed for each curve. For example, for the cases where PUO=20% and 25%, reserving 40% of the total capacity yields the highest net profit of 1,330 and 1,482 units, respectively. For the case where PUO=30%, reserving 45% yields the maximum net profit of 1,605 units. Recall that the case where PRC=0% implies the FCFS policy. Figure 2 shows that, for the case of PUO=30, the net profit can be almost doubled compared to the FCFS policy. Similar results were obtained in the cases where $p_u = 2$ and $q_u = 2$, $p_u = 2$ and $q_u = 3$, and $p_u = 3$ and $q_u = 2$.



<Figure 3> Comparison of order acceptance rate

Figure 3 shows the changes in the acceptance rate of urgent and regular orders for the cases where PUO=20%, 25%, and 30%. PRC also varies from 0% to 50%. Note here that the results in Figure 3 are independent of the profit/loss parameters. Instead, the acceptance rate can be used as a decision criterion as to how much of the capacity should be reserved for urgent orders for various PUO values. This graph also shows far excessive reserved capacity (e.g., PRCs higher than 25% with PUO=20%) contributes little to accepting more of the urgent orders. The same observation is made for the case at PRCs higher than 40% with PUO=25%. It should be pointed out that the profit/loss parameters be determined by evaluating not only profit but also potential marketing and management strategies.

4. Conclusions

In this paper we introduced the concept of capacity reservation to cope with volatile orders with short lead times for MTO firms; and illustrated its impact using computer simulation. Simulation results show that the reserved capacity scheme appears to outperform simple rules of thumb (FCFS) in terms of the number of accepted orders and the total profit attained. The simulation result may vary as the changes of parameters such as portion of urgent orders, average profit ratio of urgent orders to regular orders, and distribution of due dates.

A potentially fruitful area for subsequent research is an extension with determining the optimal level of reserved capacity for a changing level of urgent orders, or changing average profit ratio of urgent orders to regular orders, or changing probability distribution of due dates of urgent and regular orders. Once a procedure to determine the optimal reserved capacity level is established, then the level can be easily changed in the scheduling software; thereby effectively accommodating the scheduling mechanism to the dynamically changing production environment. The operation of reserved capacity we propose is generally applicable to any order based manufacturing industry. Detailed implementation may be changed according to the characteristics of specific industry.

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