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(Citation)
Procedia CIRP,93:933-937

(Issue Date)
2020-09-22

(Resource Type)
journal article

(Version)
Version of Record

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 93 (2020) 933–937

www.elsevier.com/locate/procedia

53rd CIRP Conference on Manufacturing Systems

A Proposed Production Decision Method for Order Planning Considering Decision Criteria of Multiple Organizations

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Abstract

Organizations in manufacturing industries, such as factories, salespersons and customers, have respective decision criteria to determine order quantities and production schedules in order planning. In our group, a production decision method that adjusts order quantities and decides the production schedule to maximize the overall profit of an organization in consideration of the customers' credibility has been proposed. In this paper, the proposed method introduces the order aggregation period for arranging the customers' inquiries to determine the order quantity and production schedule while reducing the tardiness of product delivery. A computational experiment is performed to evaluate and discuss the effectiveness of the proposed method.

Keywords: Decision making, Order Planning Problem, aggregation period, credibility

1. Introduction

In manufacturing industries, the majority production style has shifted from small-mix high-volume production to high-mix low-volume production to respond more flexibly to consumers' needs [1]. As a result, the market objective has changed to shortening due dates and product life cycles [2]. Also, due to the development of information and communications technology (ICT), the current status of the manufacturing equipment and production items embedded with smart sensing devices can be obtained using Internet of Things (IoT) technology [3]. By utilizing these technologies, customers can access information about the production condition easily. As a result of this situation, industries have to constantly release new products to the market and to deliver them with short period to customers. To realize the improvement of productivity, it is necessary to establish a decision-making mechanism that can respond to consumers' needs quickly. The relevant issues are to match existing demands for reducing product inventory, shorten lead time, estimate due dates accurately, launch new products rapidly, and manage individual specifications flexibly through mass customization [4]. To solve these problems, it is necessary to improve production efficiency with rational production scheduling and to properly adjust the gap between customers' needs and due date estimation by the sales department.

In the relevant research, an order acceptance and scheduling problem has been proposed by Guerrero and Kern [5]. This is defined as the joint decision concerning which orders to accept for processing and how to schedule them. Various studies have been conducted to address this problem by focusing on the profit maximization, cost minimization and so on [6-8].

10.1016/j.procir.2020.04.079

In our group, an order planning method that determines the due date and production scheduling by considering the relationships among multiple groups such as customers, salespersons, and factories was proposed [9, 10]. This order planning method introduced a value of customers' credibility to the salesperson. The salespersons determined the possible order quantity and due date estimated from the information of production schedule at the previous ordering period as soon as possible after receiving the orders from the customer [10]. The credibility changes according to the tardiness to customers and is used to adjust the order quantity. However, the orders requested by the customer early in the ordering period are preferred to the orders later in the period, and then the tardiness of the latter orders will gradually increase. In this paper, we introduce the order aggregation period, in which the salespersons collect the customers' order before adjusting the order quantity and production scheduling to reduce the risk of tardiness of product delivery. The effectiveness of this aggregation period is evaluated by a computational experiment.

2. Target Model

In this study, our target industry model has multiple customers, salespersons, and one factory, as shown in Figure 1. One ordering period is defined as the lead time from a customer's inquiry to delivery. Each organization of this model is defined as follows.

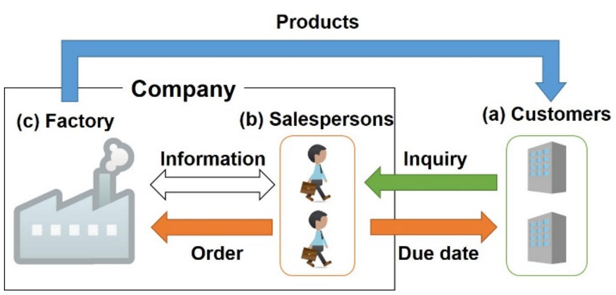

Figure 1: Overview of relationships in the target industry model. In this model, there is one factory and multiple salespersons and customers.

(a) **Customer:** Each customer orders the desired production items and the quantity of the items from the salesperson. Each customer has a degree of credibility to the salespersons, which affect and update the previous order conditions. The order quantity is determined by the degree of credibility and the answered due date from the salesperson. The degree of credibility varies depending on the occurrence situation of the tardiness from the due date of the products' delivery. When the credibility reaches the lower limit, the customer temporarily stops to orders at the subsequent ordering period.

(b) **Salespersons**: Salespersons estimate due dates in response to customers' order inquiries and desired due dates. Based on the desired due date of the customer, order quantity, and the information on the production schedule at the previous ordering period, the answered due date and quantity for the customer is decided. When an increased order quantity per ordering period is estimated, the tardiness of the product delivery increases easily.

(c) **Factory:** The factory creates a production schedule for the orders from salespersons per ordering period and manufactures products. This study targets multi-stage flow shops.

3. Proposal of a Production Decision Method Considering Order Aggregation Period

In this section, the proposed production decision method introducing an order aggregation period is explained.

3.1 Notation

In this section, the notations used in this paper are shown as follows:

- s: Salesperson (s=1,⋯,S)
- c: Customer (c=1,⋯,C)
- p: Order period (p=1,⋯,P)
- T: The number of time slots in one ordering period [Time Slot (TS)]
- $Q_{p,c}$: Desired order quantity of customer c in period p
- $Q'_{p,c}$: Answered order quantity of customer c in period p
- $CR_{p,c}$: Degree of credibility to salespersons by customer c in period p
- BQ_c: Standard order quantity of customer c
- $OT_{p,c}$: Order inquiry time by customer c in period p
- $AT_{p,c}$: Allowable time for order of customer c in period p
- $PD_{p,c}$: Desired due date of customer c in period p
- $AD_{p,c}$: Answered due date of customer c in period p
- $DD_{p,c}$: Decided delivery date of customer c in period p
- $d^{CRD}_{p,c}$: Tardiness of product delivery to customer c in period p

In addition, the notations used in scheduling are shown in as follows:

- j: Job number (j=1,⋯,J)
- k: Stage number (k=1,⋯,K)
- $T_{p,j}$: Tardiness of job j in period p
- MS_p: Makespan in period p
- $PT_{p,j,k}$: Processing time of stage k of job j in period p
- $ST_{p,j,j',k}$: Setup time from job j to job j' at stage k in period p
- $D_{p,j}$: Due date of job j in period p
- $s_{p,j,k}$: Start time of stage k of job j in period p.This value is decision variable.
- $ET_{p,j,k}$: End time of stage k of job j in period p
- ITT_p: Total tardiness acquired by solving the production scheduling for minimizing total tardiness in period p
- IMS_p: Makespan acquired by solving the production scheduling for minimizing makespan in period p
- α: Weight factor of objective function
- $x_{p,j,j',k}$: The decision variable that is 1 if the process k of job j in period p is prior to the process k of job j', and otherwise is 0

3.2 Introduction of order aggregation period to production decision method

In this paper, the order aggregation period *AP* is introduced in our proposed method to avoid the situation which the orders requested by the customer early in the period are preferred to the orders later in the period and reduce the risk of tardiness of product delivery. In this order aggregation period *AP*, the customer's order is not replied to as soon as the salespersons receive the orders, and the salespersons keep the orders throughout *AP*. At the end of the order aggregation period, the salespersons decide the quantities and due date of the order that has the highest priority. The larger *AP* is, the more high-priority orders can be received. The smaller *AP* is, the more rapidly the salespersons can communicate the order quantity and due date to the customers.

The order adjustment introducing the order aggregation period is performed as follows:

(i) The unanswered order that has the highest priority of the orders in the aggregation period is selected.

(ii) The salespersons obtain the quantity of the scheduled products up until the desired due date of the selected order.

(iii) The maximum production quantity until the desired due date is estimated using the number of scheduled products. When the maximum production quantity exceeds the desired order quantity, the salesperson adjusts the desired order quantity to the customer. When the desired order quantity exceeds the possible production quantity, the salesperson adjusts the possible production quantity to the customer.

(iv) If there is not any unanswered order, then finish. Otherwise, go to (i).

In this paper, the possible production quantity is estimated by the number of scheduled products without considering the load status of the factory. It also does not take into consideration the setup time.

3.3 Algorithm of the Production Decision Method Considering the Order Aggregation Period

The algorithm of the proposed production decision method considering the order aggregation period is shown in Figure 2. As an initial setting, the period p is set to 0 and time t is set to 1.

STEP 1: Customers request an order with a desired due date and quantity to the salespersons. The desired order quantity is determined by the following equation (1), and the due date is determined by the following equation (2):

$$Q_{p,c} = BQ_c \times CR_{p,c} \quad (1)$$

$$PD_{p,c} = p \times T + OT_{p,c} + AT_{p,c} \quad (2)$$

STEP 2: If time counter t equals aggregation period *AP*, the salespersons communicate the order quantity and due date to the customers. The procedures for adjusting answered orders are described in section 3.2.

STEP 3: The customers adjust the order quantity considering the communicated quantity and due date, and then they order.

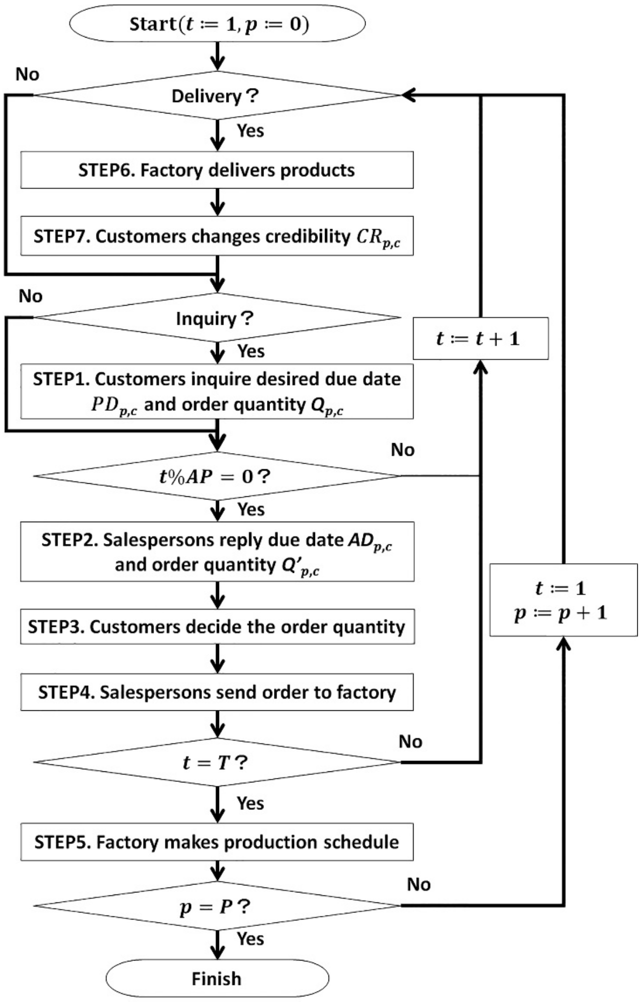

Figure 2: Algorithm of proposed production decision method.

In this paper, the customers accept the answered order quantity and due date and change the desired order quantity and due date.

STEP 4: The salespersons send the order information from the customers to the factory. If time t is the same as one ordering period T, proceed to **STEP 5**. Otherwise $t := t + 1$ and proceed to **STEP 6**.

STEP 5: If time t equals one ordering period T, the production schedule is created. The factory divides the input orders from the salespersons into multiple jobs and formulates a multi-stage flow shop scheduling problem. The production scheduling problem is solved using optimization solver CPLEX 12.6.3 (IBM) [11]. The formulation of multi-stage flow shop scheduling is shown in section 3.4. If the period p equals P, then finish.

STEP 6: If the time t equals delivery date $DD_{p,c}$, the factory delivers the finished products to the customer.

STEP 7: The customer who receives the products changes the credibility $CR_{p,}$ in consideration with the tardiness of product delivery to the customer $d_{p,c}^{CRD}$. If tardiness $d_{p,c}^{CRD}$ according to equation (3) occurs, the credibility $CR_{p,}$ decreases. Change in the credibility $CR_{p,}$ of customer c in period p is expressed by equation (4).

$$d_{p,c}^{CRD} = \max(0, DD_{p,c} - AD_{p,c}) \quad (3)$$

$$CR_{p,c} = \begin{cases} CR_{p,c} + a_{CRI} & (d_{p,c}^{CRD} \leq 0) \\ \max(0, CR_{p,c} - r_{CRD} \times d_{p,c}^{CRD} & (d_{p,c}^{CRD} > 0) \end{cases} \quad (4)$$

3.4 Formulation of K-stage flow shop scheduling

To solve the K-stage flow shop scheduling problem in **STEP 5**, the optimization problem is formulated as follows:

$$\min \quad \alpha \frac{\sum_{\forall j} T_{p,j}}{ITT_p + 1} + (1 - \alpha) \frac{MS_p}{IMS_p + 1} \quad (5)$$

$$\text{where} \quad T_{p,j} = \max(0, s_{p,j,K} + PT_{p,j,K} - D_{p,j}) \quad (6)$$

$$MS_p = \max(s_{p,j,k} + PT_{p,j,k} - ET_{p,k}) \ (\forall j, \forall k) \quad (7)$$

$$ET_{p,k} = \max(s_{p,j,k} + PT_{p,j,k}) \ (\forall j) \quad (8)$$

$$\text{s.t.} \quad s_{p,j,k+1} \geq s_{p,j,k} + PT_{p,j,k} \quad (9)$$

$$s_{p,j',k} \geq s_{p,j,k} + PT_{p,j,k} + ST_{p,j,j',k} \quad (\forall j, \forall j'(\neq j), \forall k) \ (if \ x_{p,j,j',k} = 1) \quad (10)$$

$$s_{p,j,k} \geq ET_{p,k} \ (\forall j, \forall k) \quad (11)$$

$$s_{p,j,k} \geq 0 \quad (12)$$

$$x_{p,j,j',k} + x_{p,j',j,k} = 1 \ (\forall j, \forall j'(\neq j), \forall k) \quad (13)$$

$$\mathrm{x}_{p,j,j',k} \in \{0,1\} \ (\forall j, \forall j'(\neq j), \forall k) \quad (14)$$

$\mathrm{x}_{p,j,j',k}$ is the decision variable, and when this value is 1, job j at stage k in period p precedes the job j'. When this value is 0, job j' at stage k in period p precedes job j. $s_{p,j,k}$ is the integer decision variable which shows the processing start time of job j at stage k in period p. Objective function (5) is minimization of a weighted sum of total tardiness at period p as shown in equation (6) and total makespan at period p as shown in equation (7). Equation (8) is the finish time of each job j. Equations (9) ~ (12) are constraints. Constraint (9) guarantees that the finish time of job j at stage k is earlier than the start time of job j at stage k+1. Constraint (10) limits the number of jobs that can be processed at one time. Constraints (11) and (12) represent that start time is after the end time of the previous period. Constraint (13) ensures that the precedence relation of jobs is selected by either of two.

4. Computational Experiment and Discussion

To evaluate the influence of the order collection term of the proposed order adjustment technique, we performed a computational experiment. In this experiment, a sensitive analysis for order collection terms was performed.

4.1 Experimental conditions and evaluation criteria

The experiment was performed with the following conditions:

- The number of customers (C): 10
  Of the customers, 5 were higher-priority than the other 5.
- The number of salesperson (S): 10
- The number of ordering period (P): 10
- The number of time slots in each ordering period (T): 100 [TS]
- The number of job stages (K): 2
- The number of product types : 5
- Setup time due to change of product type ($ST_{p,j,j',k}$): 2
- Standard order quantity of customers ($BQ_{p,c}$): 20
- Order inquiry time ($OT_{p,c}$): [1, 100] [TS]
- Customer allowable time ($AT_{p,c}$): [0, 20] [TS]
- Initial credibility of customer ($CR_{0,c}$): 1.0
- Range of customer credibility ($CR_{p,c}$): 0.0 ≤ $CR_{p,c}$ ≤ 1.0
- Rate of decrease in order quantity (r_{QD}): 0.04
- Amount of customer's credibility increase when the order's products can be delivered within the answered due date (a_{CRI}): 0.2
- Reduction rate of credibility at the time of tardiness occurrence (r_{CRD}): 0.02
- The number of trials: 5 each AP

Each product is ordered for two in ten customers. To set the priority of orders, the orders that are ordered from high-priority five customers are set to be higher-priority orders. In these high priority orders, the quantity and due date of the orders is decided prior to other orders.

The evaluation criteria were as follows:

- TO: Total order quantity
- DL: Average tardiness per order [TS]
- AC: Average final credibility
- AL: Average lead time from customers' inquiry to salespersons' reply [TS]

4.2 Evaluation result of proposed method with different aggregation period

Figure 3 shows the values of the valuation criteria for each answered period *AP*. Figure 4 shows the average of total quantity with priority and normal orders. The ratio of *AL* to *AP* (except for *AP* = 0) is around 0.40.

The longer *AP*s are, the smaller the total order quantity *TO* and the average tardiness per order *DL* are, and the bigger the average final credibility *AC* is, as shown in Figure 3 (a-c). The reason for a decrease in *TO* is that the quantity of normal orders is reduced with an increase of *AP*, as shown in Figure 4. Also, it will be easy to deliver the products before the due date as the *AP* increases. As a result, the average final credibility *AC* increases. The average lead time from customers' inquiry to salespersons' reply, *AL*, increases as the *AP* increases. This result has a close correlation with the increase of *AP* within an expected result. The results of Figure 3 (d) indicate that it is possible to provide a rapid reply to the customer when the *AP* is reduced.

5. Conclusion

In this paper, a production decision method considering the order aggregation period is proposed. By introducing the order aggregation period *AP*, salespersons can select higher-priority orders. The results of the computational experiment show that it is possible to communicate order quantity and due date to customers rapidly as the *AP* is reduced. Also, in the case that the *AP* is longer, the number of high-priority orders increases, and then the credibility also increases. As a future task, the scheduling periods for collecting the orders in the factory will be introduced into the proposed method.

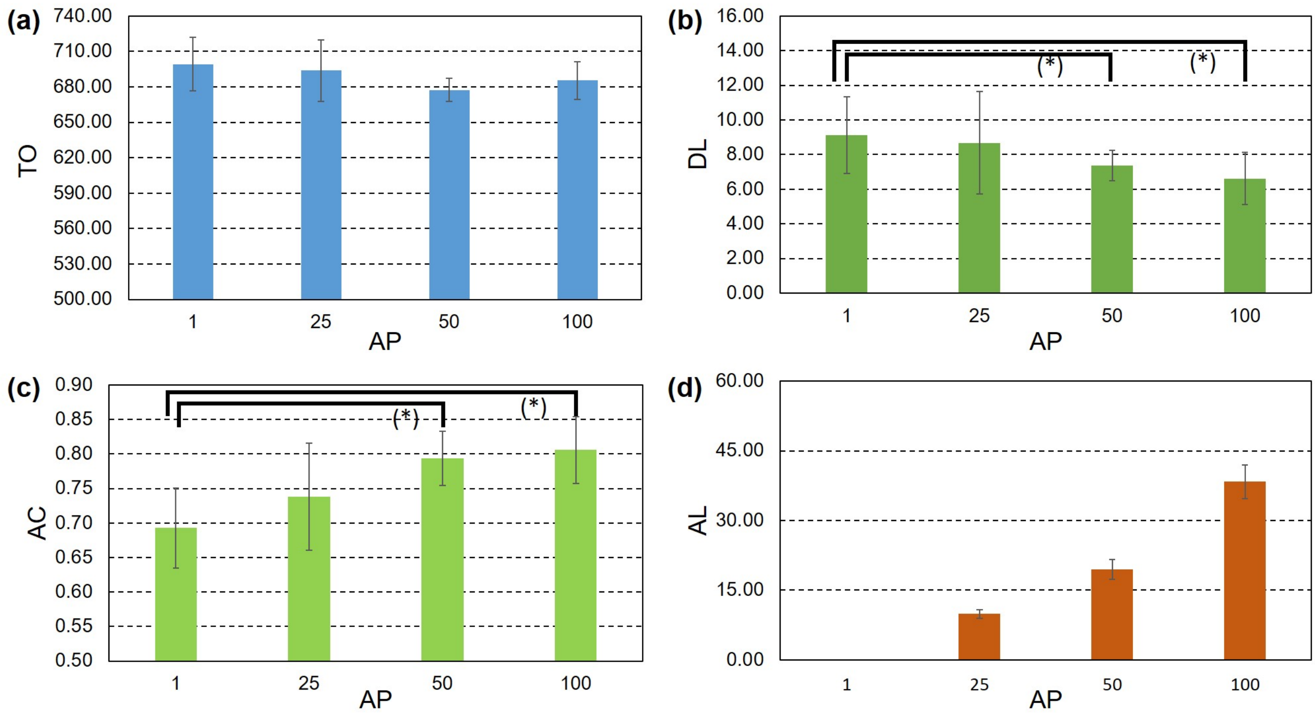

Figure 3: Results of several criteria with different AP. (a) Total order quantity (TO), (b) Average tardiness per order (DL), (c) Average final credibility and (d) Average lead time from customers' inquiry to salespersons' reply (AL). The error bars denote the standard deviation. (*): The level of significance is $p < 0.05$.

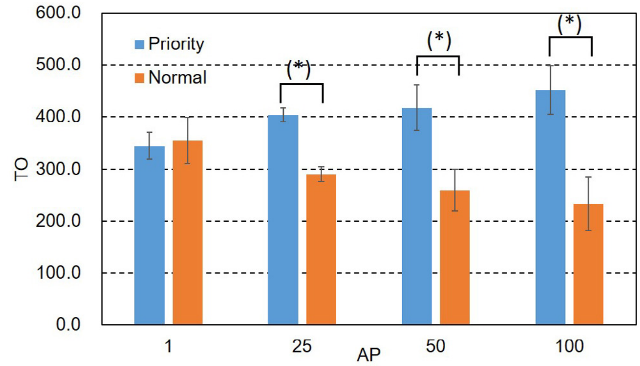

Figure 4: Results of average total order quantity with high-priority and normal orders. The error bars denote the standard deviation. (*): The level of significance is $p < 0.05$.

Acknowledgements

The authors thank Dr. Susumu Fujii for providing useful advice in this research project.

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