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DUE DATE ASSIGNMENT OF MULTI-PRODUCT IN MAKE-TO-ORDER SUPPLY CHAINS

Haruki TAKAHASHI, Ibuki SHISHIDO, Sumika ARIMA

Abstract: *This paper introduces an optimization method of due date assignment (DDA) for make-to-order (MTO) production systems. The due date assignment (DDA) in MTO system takes an important role to balance and improve both the due date satisfaction and process efficiency as trade-offs for each other. The proposed method is to work for various load volume and order fluctuations as extended version of an existing DDA method which has considered the customers' importance. We examine the performance of the proposal DDA method to combine with Hybrid flowshop Scheduling (HFS) for a typical built-to-order production system. Actual company data and discrete event simulations are used for the numerical performance evaluation. In particular, the proposed DDA method can perform well with effective multi-objective HFS engine that can handle HFS problems of a practical scale of several hundred jobs. This is because the DDA method, adapted to the order characteristics of the real data, was able to reproduce the various load volume and order fluctuations better than proposed methods.*

Key words: *Due date assignmen、Make to order、Hybrid flowshop Scheduling、supply chain management.*

1. INTRODUCTION

Supply chain disruption caused by the global spread of Covid-19 has made due date assignment (DDA) more important and challenging for make-to-order (MTO) production systems. APS (Advanced Planning and Scheduling), a typical scheduling method for order-based production, was created as a simple method for manufacturers to respond to due date based on product specifications presented by customers. Based on simple rules of feedback/feedforward and shortest processing time order, realistic planning can be calculated in a short time [1]. Other optimizations and introduction of supply-chain perspectives are also progressing, but many of them remain in time-based discussions. It is important to consider customer information, time changes in production load, cost aspects in addition to the time axis when answering due date. At the same time, since all customers/all orders are not of the same importance to the company, the importance is defined according to the order quantity and the order amount. It is an effective means for considering the long-term profit of the company to assign an early due date to customers with high importance and a relatively late delivery date to customers with low importance [3].

In this research, we use actual data from companies that conduct multi-product order production/hybrid flowshop scheduling (HFS) to verify the effectiveness of DDA methods that extend Weighted SLACK（WSLK） [3]. In that case, numerical verification was carried out in combination with heuristic algorithm which extended the n-Gupta method corresponding to n-process HFS of multi-product order production.

2. PROBLEM DESCRIPTION AND PREVIOUS WORKS

2.1 Problem description

In this research, we are focusing on a company T that produces many kinds of industrial printing machinery on order. Company T provided data on order performance, sales performance, standard hours of work, and production process. In this study, the order date, customer code,

manufacturing number, product name, and total slip sales amount among the order performance data and sales performance data are used. In addition, the production line of the company T is composed of three processes of design, manufacturing, and inspection from standard hours-of-work data and production process data, and 5, 2, and 2 machines are given respectively. There are four types of products, each with a different production time assigned to each process. The data used is from 2011 to 2019, handling 953 orders. The data after 2020 were rejected because the data was biased due to the influence of Covid-19.
In addition, the production line of the company T is composed of three processes of design, manufacturing, and inspection from standard hours-of-work data and production process data, and 5, 2, and 2 machines are given respectively. There are four types of products, each with a different production time assigned to each process. The production time per day is 8 hours, and the factory shall not be in operation on Saturdays and national holidays in Japan.

Table 1

Production process and number of machines

	Process1	Process2	Process3
Number of machines	5.0	2.0	2.0
Product1	3.0	10.0	15.0
Product2	5.0	10.0	9.0
Product3	4.0	9.0	2.5
Product4	4.5	32.0	11.0

2.2 Past methods

In this study, the following two existing meth ods are used.

Weighted SLACK [3]

Weighted SLACK (WSLK) is a delivery time setting method that considers customer weighting and time changes in production load. TPT is the total processing time of the job to assign the delivery date and is defined for each product. Using the results of 3.2 customer segmentation, it is possible to assign delivery dates according to importance by giving small coefficients to important customers and large coefficients to high-importance customers. Moreover, the delivery date can be set in consideration of the time change of the production load by $Pavg(\alpha days)$. In this study, α is set to 14. The reason for this setting is that, first, there were orders for at least one job within the past two weeks of the order date for more than 95% of jobs, and second, viewing past orders at two-week intervals would not be affected by the bias of orders due to the day of the week. k is a parameter and is responsible for adjusting the delivery length.

$$(Due\ Date) = TPT + X \times Pavg(\alpha days) \times k. \quad (1)$$

TPT: Total Processing Time
X: Weighting factor given according to customer criticality [0.5:1.5]
$Pavg(\alpha days)$: Average processing time for jobs ordered in the past α days.
k: parameters

n-Gupta method [4]

In this study, n-process Gupta algorithm, which has high performance and practicality, is used among previous studies on n-process HFS. The n-process Gupta algorithm is a heuristic algorithm which solves the problem of minimizing the objective function shown by Equation 2 and extends the local search. As a feature, the scheduling objective function is multipurpose including four indices that make tradeoffs, and each term is given an arbitrary weight so that relative importance can be adjusted. Schedule job ordering uses an insertion and iteration method.

$$minimize.\ F = \Sigma(uiEi + viTi + wiCi + zidi). \quad (2)$$

$Where.\ ui, vi, wi, zi$: weighting factor
Ei: Penalty for early completion due date of job i
Ti: penalty for missed delivery of job i
Ci: cycle time for job i
di: length of due date of job i

3. PROPOSED METHOD

This study consists of the following three steps

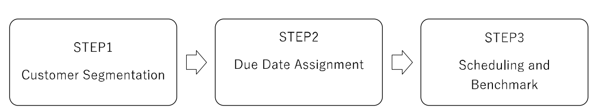

Fig. 1. Process of this study

3.1 Step1 Customer Segmentation

Customers are grouped according to importance by using the k-means method of a clustering method. 233 customers/760 orders received between 2011 and 2017 are used. The features used for clustering were four values based on the data obtained with the preceding study on clustering for business customer segmentation [5].

- Order Count
- Total expenditure
- Number of past order delivery delays
- Number of past sales order deadlines

The two indexes of the number of orders / total expenditure amount define that the higher the value, the more important the customer to the enterprise. The number of delivery delays is a situation that damages the trust of customers from a corporate perspective, and it is necessary to restore the trust by presenting the delivery date earlier than other customers in future orders and achieving delivery date compliance [6]. Therefore, the customer with the large number of times of delivery delay is defined as the customer with higher importance. In that the number of delivery slippage affects the product inventory holding days and the cash flow of the customer, the customer with the number of delivery slippage like delivery delay is defined as the customer with higher importance. Using the Elbow Method, customers from 2011 to 2017 were classified into four groups, and 101 customers and 193 orders from 2018 and 2019 were classified into five groups, including new customer groups. The larger the group number, the more important the customer. The group 1 represents a new customer, and the value of each index is larger in the group 5 than in the group 4.

Table 2

Customer grouping

	Number of orders	Total amount spent	Number of delivery delays in past orders	Number of delivery delays in past orders
group1	0	0	0	0
group2	few	little	0	few
group3	few	little	few	few
group4,5	many	numerous	many	many

3.2 Step2 Due Date Assignment

In the data set used in this study, there are about 5% of all orders that have no orders in the past 14 days, that is, jobs with $Pavg(14days) = 0$. It can be considered that these jobs do not change the number of delivery dates even if the value of the parameter k is changed and cause delivery delay. Therefore, considering that the minimum value of $Pavg(14days)$ at a value other than $Pavg(14days) = 0$ is 2.21, the job of $Pavg(14days) = 0$ is replaced by $Pavg(1414days) = 2$ to apply WSLK. The delivery date allocation is defined as WSLK2 and the performance is compared with the existing method WSLK.

$$(Due\ Date) = TPT + X \times Pavg(\alpha days) \times k. \quad (3)$$

TPT: Total Processing Time
X: Weighting factor given according to customer criticality [0.5:1.5]
$Pavg(\alpha days)$: Average processing time for jobs ordered in the past α days. But replace job 0 with 2.
k: parameters

3.3 Step3 Scheduling and Benchmark

The scheduling uses the n-process Gupta algorithm shown in 2.2. The order data for 2018-2019 will be scheduled for three months. The results of scheduling are evaluated using the following five indicators.

- Average Delivery date compliance rate
- Average Delivery days late
- Average Delivery days early
- Average cycle time
- Average Makespan

In this study, as a comparison method to verify the effectiveness of WSLK2, the comparison was carried out by the delivery time random reallocation (RRDD) and WSLK. Delivery Date Random reassignment is a method for creating a list of delivery date lengths for all orders assigned in WSLK2 and assigning them randomly. This comparison method can be used to verify the effectiveness of considering the time change of production load, which is a characteristic of WSLK2. Three datasets were created to prevent random bias and compared.

4. NUMERICAL STUDY

Using order data from 2018 to 2019, we performed numerical experiments by multiplying the n-process Gupta algorithm, three delivery methods (WSLK2, WSLK, RRDD), and five patterns of data sets. In this paper, we compare and evaluate the results of scheduling using the delivery dates generated by k=5, 6, 7, 8, in which the difference of each data set of 5 patterns is clearly shown. Five comparison indices shown in 3.3 are used for comparison/evaluation.

Average Delivery date compliance rate

Average delivery time compliance rate is the percentage of jobs that are delivered on time and is one of the most important indicators in inter-company transactions. From the table, only WSLK2 has achieved 100% delivery compliance rate after k=7. Therefore, it can be said that WSLK2 is the best method among the three methods in terms of delivery date compliance rate. When comparing WSLK2 and WSLK, the advantage of WSLK2 is proof of the effectiveness of replacing a job with $Pavg(14days)$ =0 with $Pavg(14days)$ =2. The advantage of WSLK" when comparing WSLK2 and RRDD is proof that it is effective to respond to the time change of production load which is characteristic of WSLK2. Also, comparing WSLK and RRDD, RRDD shows superior results. It can be said that this indicates the risk of using WSLK as it is in products with few orders such as multi-product small-lot production, although WSLK can respond to the change in production load over time.

Table 3

Average Delivery date compliance rate

	k=5	k=6	k=7	k=8
WSLK2	97.91%	98.45%	100.00%	100.00%
WSLK	89.97%	90.51%	91.11%	91.54%
RRDD 1	97.57%	97.55%	99.57%	99.57%
RRDD 2	95.72%	97.33%	98.19%	98.74%
RRDD 3	95.72%	97.33%	98.19%	98.74%

Average Delivery days late

The Average Late Delivery Days represents the average value of the past delivery time of a job that has been late. Therefore, it is necessary to keep the value as small as possible because the average delivery delay days leads to the reduction of trust between companies and the delay of work on the ordering side. From the table, the average delivery delay date tended to be the same as the delivery date compliance rate. The magnitude of the value of WSLK stands out among them. This is a factor that there are 5% of all jobs with $Pavg(14days)$ =0 in WSLK, and those jobs do not affect delivery time even if the value of the parameter k is raised.

Table 4

Average delivery days late

	k=5	k=6	k=7	k=8
WSLK2	1.13	0.63	0.00	0.00
WSLK	2.92	2.54	2.29	2.17
RRDD 1	0.88	1.13	0.38	0.25
RRDD 2	1.38	0.94	0.63	0.38
RRDD 3	1.13	1.38	0.25	0.25

Average delivery days early

Average delivery days early shows how many days earlier a job completed earlier than the due date on average. When jobs are completed early, inventory holding costs are incurred until company's ship. Therefore, for companies, Average delivery days early should be as few as possible. Looking at the table, WSLK2 shows the best results. The reason that WSLK2 is superior to RRDD is whether it responds to the change in production load over time. Although delivery compliance and Average delivery days early are trade-off indicators, the dominance of WSLK2 in both indicators means that WSLK2 is better able to respond to changes in production load over time.

Table 5

Average delivery days early

	k=5	k=6	k=7	k=8
WSLK2	8.12	10.13	12.01	13.78
WSLK	8.43	10.48	12.49	14.27
RRDD 1	9.26	11.39	12.95	14.46
RRDD 2	9.50	10.85	13.01	14.58
RRDD 3	8.90	11.03	12.70	14.46

Average cycle time

The average cycle time represents the average time from the start of production to the end of production of each job. In other words, the fact that the average cycle time is long indicates that waste such as waiting time and setup has occurred in the production process, and the shorter cycle time is preferable. Looking at the table, there is no significant difference in comparison between the three delivery methods. It is said that the longer the delivery time, the shorter the cycle time. Therefore, it is thought that there was no big difference in this scheduling which is not much different in delivery length.

Table 6

Average cycle time

	k=5	k=6	k=7	k=8
WSLK2	5.38	5.29	5.27	5.28
WSLK	5.38	5.29	5.28	5.24
RRDD 1	5.28	5.27	5.30	5.35
RRDD 2	5.30	5.45	5.37	5.38
RRDD 3	5.26	5.10	5.17	5.12

Average Makespan

The average Makespan represents the average number of days from the start of production during the period (every three months) to the end of production of all orders. Since the average Max Pan indicates that the performance of the whole scheduling is better the shorter it is, the shorter it is better. The results shown in the table show the number of working days in the factory excluding Saturdays and national holidays. Looking at the table, it can be said that there is no big difference between the three delivery date setting methods as well as the average cycle time. 3. It is considered that the difference in delivery length between these delivery date setting methods is small.

Table 7

average Makespan

	k=5	k=6	k=7	k=8
WSLK2	59.00	59.38	60.50	62.25
WSLK	59.00	59.38	60.50	62.25
RRDD 1	59.25	59.75	61.00	62.88
RRDD 2	59.13	59.25	59.63	61.63
RRDD 3	58.75	58.38	60.88	63.63

Optimal Value for Parameter k

In this chapter, the results of the previous section show that WSLK2 is the best of the three delivery methods, and then consider the optimal k-Value. Table summarizes five evaluation indices in WLK2. At K=7,8, the average delivery compliance rate, and the average delivery delay date are optimum values respectively. On the other hand, the number of days is increased with the increase of the value of k in the average delivery delay days and the average Makespan. Therefore, it can be said that k=7 is superior in terms of the average delivery time and average Max Pan. In summary, the best result is that the setting of WSLK2 k=8 under the setting of the problem of this research.

Table 7

ptimal value for Parameter k

	k=5	k=6	k=7	k=8
Average Delivery date compliance rate	97.91%	98.45%	100.00%	100.00%
Average Delivery days late	1.13	0.63	0.00	0.00
Average delivery days early	8.12	10.13	12.01	13.78
Average cycle time	5.38	5.29	5.27	5.28
Average Makespan	59.00	59.38	60.50	62.25

5. CONCLUSION

This study aims to improve performance when combining WSLK (Weighted SLACK), which is a delivery time setting focusing on the importance of customers and the time change of production load in multi-product order production, and WSLK2, an extended proposal method, with the n-Gupta method of n-process HFS algorithm. For the numerical experiment, we used data from Company T, which is producing many kinds of industrial printing machine parts. The following results were obtained by numerical experiments.

- WSLK2 showed the best results in all of the average delivery compliance rate/average delivery delay days and average delivery delay days which are considered to be a trade-off relationship. This is since WSLK2 corresponds to the time change of the production load, and that all the jobs changed the formula so that the delivery time length increased by the increase of the parameter k.
- There was no significant difference between the average cycle time and the average Makespan between the three delivery methods.
- In this numerical experiment, it is concluded that the optimum value of k is 7. However, since the optimal k-Value varies depending on the product lead time and production load, it is necessary to calculate the optimal k-Value every time based on scheduling.

In this study, the characteristics of industrial printing machine parts are high price and low order quantity, and WSLK2, a proposal method which improved WSLK, showed good results.

As future research, it is desirable to consider not only the expansion of the method not depending on the parameter k, but also verification in industries with large order quantity and combination with different scheduling methods.

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ATRIBUIREA DATEI DE SCADENȚĂ A MULTI-PRODUSELOR ÎN LANȚURILE DE APROVIZIONARE MAKE-TO-ORDER

Această lucrare introduce o metodă de optimizare a atribuirii datei scadente (DDA) pentru sistemele de producție de tip "make-to-order" (MTO). Atribuirea datei scadente (DDA) în sistemul MTO joacă un rol important în echilibrarea și îmbunătățirea atât a satisfacerii datei scadente, cât și a eficienței procesului, ca un compromis între ele. Metoda propusă trebuie să funcționeze pentru diferite volume de încărcare și fluctuații ale comenzilor ca versiune extinsă a unei metode DDA existente care a luat în considerare importanța clienților. Examinăm performanța metodei DDA propuse pentru a o combina cu Hybrid flowshop Scheduling (HFS) pentru un sistem tipic de producție la comandă. Pentru evaluarea numerică a performanțelor sunt utilizate date reale ale companiei și simulări de evenimente discrete. În particular, metoda DDA propusă poate funcționa bine cu un sistem HFS multi-obiectiv eficient care poate gestiona probleme HFS la o scară practică de câteva sute de locuri de muncă. Acest lucru se datorează faptului că metoda DDA, adaptată la caracteristicile comenzilor din datele reale, a fost capabilă să reproducă diferitele fluctuații ale volumului de încărcare și ale comenzilor mai bine decât metodele propuse.

Haruki TAKAHASHI, PhD student, University of Tsukuba, System Information Engineering Research Group, s2220503@u.tsukuba.ac.jp, +81 -298-535-558, 1-1-1, Tennodai, Tsukuba city, Ibaraki pref., Japan.

Ibuki SHISHIDO, BE student, University of Tsukuba, System Information Engineering Research Group, s2011341@u.tsukuba.ac.jp, +81 -298-535-558, 1-1-1, Tennodai, Tsukuba city, Ibaraki pref., Japan.

Sumika ARIMA, Senior Lecturer, University of Tsukuba, System Information Engineering Research Group, arima@sk.tsukuba.ac.jp, +81 -298-535-558, 1-1-1, Tennodai, Tsukuba city, Ibaraki pref., Japan.