International Journal of Production Research
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tprs20

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Published online: 15 Nov 2010.

INT. J. PROD. RES., 1997, VOL. 35, NO. 12, 3379–3392

Integrating order release control with due-date assignment rules

C.-H. TSAI†, G.-T. CHANG† and R.-K. LI†‡

This study integrates order release control methods with due-date assignment rules and assesses its impact on the accuracy of inter-operation time estimation and performance of due-date assignment. The assessment is made by using an experimental design with three due-date assignment rules, three scheduling rules and three order release models. The three order release models are: (1) *Basic* model, in which three due-date assignment rules consider the order arrival time as the order release time; (2) *Control* model, in which three due-date assignment rules integrate with the order release control method developed here; and (3) *Adjustment* model, in which the control model integrates with the order release control adjustment developed here. Simulation results in this study indicate that integrating the order release control method with due-date assignment rules will significantly enhance not only the accuracy of interoperation time estimation, but also the performance of due-date assignment rules.

1. Introduction

Due date assignment is a critical element in production control, affecting both timely delivery and reduced finished goods inventory. Due dates are typically assigned either by customers or by the manufacturer. In the former situation, customers determine the due dates and the manufacturer evaluates the feasibility of meeting the due dates. Negotiation before consent by both parties is usually deemed necessary. In the latter situation, the customer due date is open and the manufacturer establishes the due dates and informs the customer. Regardless of the situation the manufacturer must determine the date to release the order and estimate the expected flowtime to either confirm the customer-assigned due date or establish a due date for the customer. The due date assignment procedure entails initially determining the order release time and then estimating the flowtime allowance of the releasing order. The order due-date is then equal to the sum of the order flowtime allowance and order release time. The calculation of this flowtime allowance is not straightforward because of the dynamic nature of many manufacturing environments in which new jobs are constantly arriving and job priorities changing. Although it would therefore be impossible to develop a system which always predicts due-dates precisely, the development of simple yet more accurate methods remains a research challenge.

Earlier research involving the due-date assignment focused on primarily comparing the due-date performance for different due-date assignment rules interacting with various dispatching rules (Conway *et al.* 1967, Elion and Chowdhury 1976, Ragatz 1989). Among the specific due-date performance measures include job lateness, job tardiness, and average flowtime. Those investigations analysed six due-date

Revision received October 1996.
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0020–7543/97 $12·00

assignment rules: (1) The total work content due date rule (TWK) estimates flowtimes as a proportion of the job's expected total processing time; (2) The number of operations due date rule (NOP) assigns flowtimes in proportion to the number of operations required for the job; (3) The constant allowance due date rule (CON) assigns a fixed flowtime allowance to all jobs; (4) The random allowance due date rule (RDM) randomly assigns flowtimes within a designed range; (5) The delay in queue due date rule (DIQ) uses the average job delay (waiting time), based on historical data and total work as the job characteristics and; (6) the jobs in queue due date rule (JIQ) assign flowtimes allowance on the basis of the total number of jobs in the system waiting to be processed on machines encountered on the job's route.

The due-date assignment rules assume the order's release time is equal to the order's arrival time. The fundamental difference among the due-date assignment rules is how to estimate the order flowtime allowance. The order flowtime allowance is based on the processing time of operations and the order inter-operation time. The order interoperation time consists of queue times, move time and waiting time. The queuing delays are caused by resource contention due to factors such as machine status, variability in processing times, variability in arrival times, and variability in batch sizes. The CON, RDM, TWK and NOP estimate the flowtime allowance without considering the machine's status information. Although JIQ and DIQ consider the shop congestion status, their flowtime allowance estimate is static, i.e. the due-date assignment rules should react to dynamically changing systems which have not yet been studied. Vig and Dooley (1991, 1993) proposed two dynamic due-date assignment rules, operation flowtime sampling (OFS) and congestion and operation flowtime sampling (COFS). Both of those investigations estimated flowtime on the basis of a sampling of recently completed orders. Their results clearly indicated that flowtime from recently completed orders provide valuable information for establishing effective due-dates in a job shop environment.

The above mentioned due-date assignment rules assume that the orders are released to the shop as they are received, thereby effectively bypassing the order release decision (Ragatz and Mabert 1988). However, as generally known, the release function controls the level of WIP inventory, and the level of WIP determines the flowtime of the orders. The higher WIP implies the longer flowtime and less delivery performance. Therefore, neglecting the order release control may bias the results of the due date assignment. Previous studies (Irastorza and Deane 1974, Lockett and Muhlemann 1978, Onur and Fabrycky 1987, Ragatz and Mabert 1988, Melnyk and Ragatz 1989, Bobrowski 1989, Philipoom and Fry 1992, Roderick *et al.* 1992, Zapfel and Missbauer 1993, Hendry and Wong 1994, Lingayat *et al.* 1995) focused on order review and release, conferring that order release function is primarily a shop floor control function. Those order release investigations aimed to provide a controlled comparison (on several dimensions of shop performance) with respect to a broad range of order release mechanisms in combination with both simple and complex dispatching rules. Order release mechanisms studied by previous researches can be classified into three groups: (1) naive rules which exercise little if any control over job release; (2) rules based on information about a particular job (such as due date, number of job operations) and possibly information about current shop congestion (such as number of jobs released); (3) rules which load jobs into the limited machine capacity available over time. Although considering the due-date assignment concept, those investigations assumed either fixed flowtime allowance or given flowtime to be a variable which depends on the shop floor loadings status (e.g. tight, medium, loose). However, flowtime estimation has received limited attention.

Order release control and flowtime estimation are the primary concern of accurately estimating the due date. Since flowtime is the sum of the order processing time and inter-operation time and the processing time can be assumed to be constant, therefore flowtime estimation entails estimating the total interoperation time. The order release should be controlled according to the system's congestion and/or other key (or constraint) resources. It is implied that the more the system and/or key resources become congested, the fewer orders should be released (i.e. delay in the order release time). However, accurately estimating the interoperation time is influenced by the system's congestion. Both are highly interactive and their interactive effects cannot be neglected in due-date assignment study.

Therefore, this study evaluates the feasibiity of accurately estimating the interoperation time if the order release control is integrated with the due-date assignment rules. An evaluation is also made as to whether the performance of due-date assignment rules can be improved if the order release control is integrated with the due-date assignment rules. Moreover, the feasibility of whether the delivery performance would be enhanced if an order release control adjustment function is added into the order release control is assessed. By assuming that the order release control method controls the system loading, this study attempts to reduce the complexity and increase the stability of the system. It is shown that flowtime can be controlled by controlling planned and released shop floor loadings. Consequently, the interoperation time can be more accurately estimated and manufacturing lead times can be reduced.

2. Order release control method

Order release control aims to control the order being released to the shop floor in time, and can be controlled by two general principles: (1) Control the workcentre queue's length and do not overload the workcentre; (2) Control the shop's total loading and do not overload the shop. According the general principles, three loading rules are defined:

Rule 1. The loading of the workcentres, before the newly released order is added, that processes the new releasing order should be below their pre-defined upper limit.

Rule 2. The current shop loading, in addition to the added loading of the new releasing order, should be below the pre-defined upper limit shop loading.

Rule 3. The current workcentre (processing the first operation of the new releasing order) – the loading, in addition to the added first operation loading of the new releasing order, should be below the pre-defined upper limit.

Figure 1 illustrates a heuristic order release control method developed on the basis of the three loading rules. The new order's planning release date is confirmed only when rule 1 and either rule 2 or 3 are satisfied. If neither one is satisfied, the new order's planning release date is forwarded to the next day and the logic is re-examined.

The orders considered for the loading computation include the released orders and planned released orders. Loading computation for those orders whose planning order release date is today is simple: merely check the current loading status. However, loading computation for those orders that cannot be released today

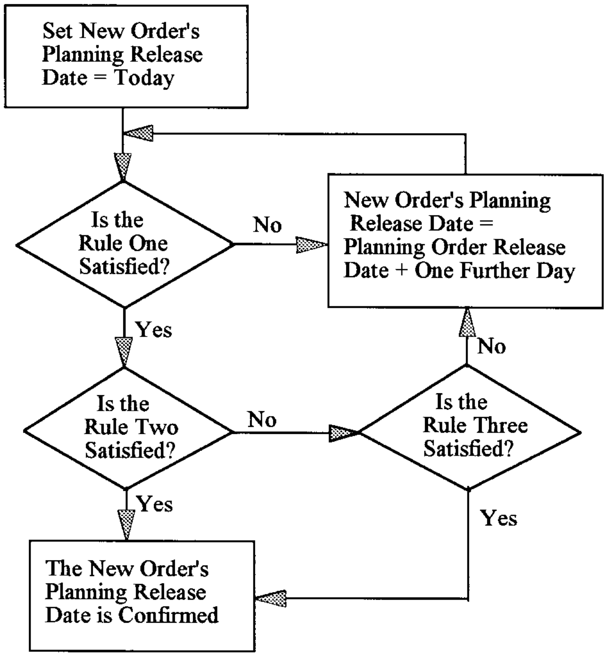

Figure 1. Logic of order release control.

(owing to the fact that none of the loading rules is satisfied) will be released at a future date. Under this circumstance, what the loading status will be at that future date is unknown. Knowing the loading status at that future date requires knowledge of the released and planned release orders' status at that future date. If the released orders at a future date have completed several operations, the loadings for those workstations having processed those completed operations should then be released as available loading at that future date. Otherwise, either partial loadings or no loading of those workcentres should be released. In this study, a heuristic algorithm, similar to the block scheduling concept (Narasimhan *et al.* 1995), is developed to accurately predict the workcentre's loading status when an order is to be released at a future date.

Step 1. Give the due-date of the order to be evaluated and determine the Quoted Flow Time (QFT). The QFT is set equal to the due date minus today. For instance, if today is day 1 and the due date of an order is on day 6, then the QFT is equal to 5 days. If it is 8 hours per day then the QFT is equal to 40 hours.

Step 2. Determine the proportional operation time rate. For instance, if an order has three operations and each operation requires processing time of 2, 3 and 5 hours respectively, the proportional operation time rate for each operation is 0·2, 0·3 and 0·5, respectively.

Step 3. Allocate the QFT to each operation on the basis of its proportional operation time rate. For instance, if the QFT is 40 hours and the proportional time rate for each operation is 0·2, 0·3 and 0·5, then the allocated QFT for each operation is 8 hours, 12 hours and 20 hours.

Step 4. Determine the ending time of each operation at each workcentre. Each operation's ending time is the cumulative time of QFT. For instance, the ending time of operation 1 is 8 hours, ending time of operation 2 is 20 hours and ending time of operation 3 is 40 hours.

Step 5. Predict the workcentre loading at the future date. Since each operation's ending time at each workcentre at a future time is determined in step 4, each workcentre's loading status for each released or planned release (future planning release is confirmed) orders at any future date can be derived by checking the ending time of each operation with the future date. Three situations occur: (1) A situation in which the ending time of the checking order's operation is before the future date suggests that the operation was completed and its allocated loading should be deducted from the workcentre. (2) A situation in which the starting time of the checking order's operation is after the future date suggests that no allocated loading is deducted from the workcentre. (3) If neither of the above two situations occurs, a linear loading deduction from the workcentre is executed. For instance, if predicting the workcentre loading after two days is desired, for the released order mentioned in the above steps, operation one's ending time is at hour 8, it is situation one. Therefore, 2 hours of allocated loading should be deducted from the workcentre and released for other planning release orders. The operation three's ending time is at hour 40, it is situation two; no allocated loading should be deducted from the workcentre. The operation two's ending time is after day two, buts its starting time can be before day two, it is situation three. Moreover, a linear loading computation $3 \times [(16 - 8)/12]$ suggests that 2 hours of allocated loading should be deducted from the workcentre and released for other planning release orders.

Step 6. Repeat steps 1 to 5 for each released and planned release orders, the workcentre and system loading can be predicted for each order to be planned at a future date.

3. Due-date assignment rules

Three different due-date assignment rules (OITS, LIQ and TWK & NOP) are evaluated in this study. The due-date assignment procedure entails initially estimating the flowtime of the arriving order and then adding the flowtime allowance to the order's release time (or the order's arrival time).

The OITS (Operation Interoperation Time Sampling) is modified from the OFS (Operation Flowtime Sampling) as developed by Vig and Dooley (1991). They contended that each order's flowtime is autocorrelated. The flowtime length of the new completed order denoted the congestion of the system status. In this study, OITS uses the average interoperation time, total number of operations and total processing time of the three recently completed orders. The mathematical expression is as follows:

$$I_i = K_1 \times H_i + K_2 \times N_i + K_3 \times P_i$$

$$Q = (Q_1/N_1 + Q_2/N_2 + Q_3/N_3)/3$$

$$H_i = Q \times N_i$$

Where

I_i	Estimated interoperation time of order *i*.
N_i	Number of operations of order *i*.
P_i	Total processing time of order *i*.
Q_1, Q_2, Q_3	Waiting time obtained from the three most recently completed orders.
K_i	Average waiting time of a single operation.
H_i	Average waiting time of order *i*.

The NOP & TWK use the number of operations and total processing time of order to estimate the interoperation time. The expression equation is:

$$I_i = K_1 \times N_i + K_2 \times P_i$$

The LIQ modified from the JIQ includes loading of those workcentres that the order must go through into the NOP & TWK equations. The expression equation is:

$$I_i = K_1 \times N_i + K_2 \times P_i + K_3 \times QL_i$$

Where QL_i is the workload of the workcentres that the order goes through.

In much of the previous research, the definition of I has been total flowtime, with a variety of alternative K values studied to determine the effect of due-date tightness. However, in this model, I is used as total interoperation time because processing time is assumed constant and becomes one of the factors influencing the interoperation time estimation. With the interoperation time I, the due date can then be determined by the following expression:

$$F_i = P_i + I_i$$

$$D_i = R_i + F_i$$

Where,

F_i	Total flowtime of order *i*.
D_i	Due-date of order *i*.
R_i	Release date of order *i*.

4. Order release control adjustment

Since the interoperation time is estimated using some historical data and control parameters, some of the values will be under-estimates, which will lead to some orders being delivered late unless appropriate remedial action is taken. The simplest approach is to release those orders early. However, how do we know which order's interoperation time is under-estimated? Since the due-date for each released order and planned releasing order in this stage is known, a backward scheduling-like checking algorithm can be applied to identify which are potential late orders.

Step 1. Give O as a set of released orders and planned releasing orders.

Step 2. Select an order O_i from the set O which has the earliest due date. Given O_{ij} is a set of operations of order O_i. Assign RD_i (order O_i's planning release date) equal to the due date of O_i.

Step 3. Schedule the last operation O_{ij} of the order O_i to its processing workcentre. Eliminate the schedule operation from the O_{ij} set and reset RD_i as RD_i minus the processing time of O_{ij}.

Step 4. Repeat step 3 until the selected order O_i has no more operation in operation set O_{ij}. Eliminate the selected order O_i from the order set O.
Step 5. Repeat the steps 2 to 4 until the order set O is a null set, then stop.

According to this work commitment algorithm, a schedule for the released order and the latest order release date for the releasing order can be derived. The fact that those released orders behind the schedule or those releasing orders' planning release date lag behind the latest order release date implies that they are potential late orders. Two actions can be taken. A high priority should be given for those potential late released orders. For those potential late releasing orders, shift the release date early.

5. Scheduling rules

Three schedules are used in this study to assess the performance of integration order release control with due-date assignment rules. There are FIFS (First in first service), EDD (Earliest due date) and T-SPT (Truncated shortest processing time). The T-SPT rule sequences jobs according to the SPT rule, except for those jobs having waited longer than a specified truncation time.

6. Experimental design

The experimental design consists of a three-phase investigation. First, a simulation model of the shop is developed and coded. Second, estimation accuracy of the interoperation time is evaluated when the order release control is integrated with the due-date assignment rules. Finally, a factorial design is used to study whether (1) the proposed integration of order release control with due-date assignment rules will improve the performance of due-date assignment, and (2) further integrating order release adjustment with order release control would increase the due-date performance. A three-factor full factorial design is used to achieve the latter task. The design includes three due-date assignment rules (NOP & TWK, LIQ and OITS), three scheduling rules (FIFS, EDD and T-SPT) and three order release models. The three order release models are: (1) Basic model, in which three due-date assignment rules consider the order arrival time as the order release time; (2) Control model, in which three due-date assignment rules integrate with the order release control method developed in § 2. This implies that the order release time is either equal to or greater than, the order arrival time. Orders are released to the shop floor based on the order release control method; and (3) Adjustment model, in which the control model integrates with the order release control adjustment developed in § 4.

6.1. *Shop model*

The shop model developed by Vig and Dooley (1991) is adopted here. The shop has five unique workcentres. Each workcentre contains one machine. The arrival of orders to the shop is random with interarrival times that are exponentially distributed with a mean of 1·2 hours. Arriving orders are assigned from one to ten operations with uniform distribution. No successive operations performed at the same workcentre are permitted. The operation time is also random variables from a 2-Erlang distribution with a mean of 1·0 hour. Further assumptions regarding the shop model are described below:

(1) A specific work centre has constant availability over time. For simplicity in modelling machine breakdowns and maintenance are not considered.

(2) The model does not include assembly operations. All orders consist of sequential operations which are independent of other orders.
(3) Each work centre is unique in the job shop.
(4) Each operation must be performed at the designated work centre. Alternative routeings are not considered.
(5) Preemption of an operation is not allowed. An order cannot be removed from a queue until the current operation at the work centre is completed.
(6) Only a single operation can be processed at a time for a particular order.
(7) Work centres can process only one operation at a time.

The computer simulation model was programmed in SLAMSYSTEM (Pritsker 1991), a simulation analysis language for modelling general systems.

6.2. *Estimation accuracy of interoperation time*

Steady-state simulation runs of 120 000 hours (i.e. 100 000 jobs completed) are generated. Of the completed orders, 5% are randomly selected as samples to ensure that the observations are approximately independent. With correlation analysis, those relative variables (shop floor and order information) that affect the quality of interoperation time estimation for basic model and control model can be found. Table 1 summarizes the analysis results. Based on those results, we can conclude the following:

Class	Symbol	Description	Correlation coefficient: Basic model	Correlation coefficient: Control model
Information about order characteristics	N	The number of operations	0·6510	0·7790
	P	The total processing time	0·4962	0·5899
Information about shop condition	L_{total}	Total machine load	0·5353	0·2404
	L_{avg}	Average machine load	0·5353	0·2404
	L_{max}	Maximum machine load	0·5214	0·2457
	Q_{total}	Total machine queue length	0·5327	0·2457
	Q_{avg}	Average machine queue length	0·5125	0·2458
	Q_{max}	Maximum machine queue length	0·4565	0·2401
Information about order's routing	RL_{total}	Total machine load in order's route	0·8242	0·5902
	RL_{avg}	Average machine load in order's route	0·8242	0·5903
	RL_{max}	Maximum machine load in order's route	0·6576	0·3329
	RQ_{total}	Total machine queue length in order's route	0·8269	0·6162
	RQ_{avg}	Average machine queue length in order's route	0·8250	0·6174
	RQ_{max}	Maximum machine queue length in order's route	0·6960	0·4776
Information about recently completely orders	Q_i	Waiting time obtained from the three most recently completed orders	0·8204	0·7948

Table 1. Correlation coefficients of information items and interoperation time.

(1) The number of information items that are significant to the interoperation time estimation for the control model are less than for the basic model. Therefore, fewer information items are required in estimating the interoperation time in a control model.
(2) Information about shop's condition is less significant in estimating the interoperation time for the control model. This finding verifies that order release control is critical in stabilizing the shop floor.
(3) Information regarding the order characteristics is critical in interoperation time for both models, particularly the number of operations.
(4) Regardless of the model, information regarding the order's route is more useful than the other information items when estimating interoperation time.

6.3. *Due-date assignment rules' parameters estimation*

Since three different scheduling rules and different order sequences will be generated, the parameter values for each interoperation time estimation equation should be estimated individually. In this paper, a regression model is used to derive the parameters' value for each interoperation time estimation equation with the input of the simulation results from the initial simulation run described in § 6.2. Tables 2 and 3 summarize the regression analysis results.

Scheduling rule	Due-date rules	Parameter value
FIFS	NOP & TWK	$I_i = 0{\cdot}172 + 9{\cdot}543N_i - 0{\cdot}160P_i$
	LIQ	$I_i = -17{\cdot}446 + 4{\cdot}742N_i - 0{\cdot}195P_i + 0{\cdot}324RL_{i,total}$
	OITS	$I_i = 0{\cdot}212 + 0{\cdot}730H_i + 2{\cdot}817N_i - 0{\cdot}197P_i$
EDD	NOP & TWK	$I_i = -7{\cdot}450 + 1{\cdot}840N_i + 8{\cdot}505P_i$
	LIQ	$I_i = -25{\cdot}344 - 2{\cdot}508N_i + 8{\cdot}433P_i + 0{\cdot}202RL_{i,total}$
	OITS	$I_i = -8{\cdot}126 + 0{\cdot}548H_i - 2{\cdot}614N_i + 8{\cdot}576P_i$
T-SPT	NOP & TWK	$I_i = 0{\cdot}595 + 1{\cdot}726N_i + 5{\cdot}018P_i$
	LIQ	$I_i = -13{\cdot}588 - 2{\cdot}050N_i + 4{\cdot}686P_i + 0{\cdot}389RL_{i,total}$
	OITS	$I_i = 1{\cdot}411 + 0{\cdot}636H_i - 2{\cdot}590N_i + 4{\cdot}916P_i$

Table 2. Parameters estimation for basic model.

Scheduling rule	Due-date rules	Parameter value
FIFS	NOP & TWK	$I_i = 0{\cdot}493 + 8{\cdot}269N_i - 0{\cdot}322P_i$
	LIQ	$I_i = -4{\cdot}795 + 6{\cdot}886N_i - 0{\cdot}289P_i + 0{\cdot}056RL_{i,total}$
	OITS	$I_i = 0{\cdot}307 + 0{\cdot}503H_i + 4{\cdot}284N_i - 0{\cdot}314P_i$
EDD	NOP & TWK	$I_i = -14{\cdot}424 + 1{\cdot}351N_i + 7{\cdot}572P_i$
	LIQ	$I_i = -16{\cdot}185 + 0{\cdot}848N_i + 7{\cdot}600P_i + 0{\cdot}009RL_{i,total}$
	OITS	$I_i = -14{\cdot}432 + 0{\cdot}068H_i + 1{\cdot}003N_i + 7{\cdot}566P_i$
T-SPT	NOP & TWK	$I_i = 0{\cdot}753 + 0{\cdot}693N_i + 4{\cdot}546P_i$
	LIQ	$I_i = -3{\cdot}442 - 0{\cdot}474N_i + 4{\cdot}536P_i + 0{\cdot}070RL_{i,total}$
	OITS	$I_i = 0{\cdot}828 + 0{\cdot}287H_i - 0{\cdot}900N_i + 4{\cdot}589P_i$

Table 3. Parameters estimation for control model.

6.4. *Experimental procedure*

Two three-factor full factorial experimental designs are used to evaluate whether the control model and adjustment model will enhance the performance of the due-date assignment rule. Experiment One compares the control model with the basic model. Experiment Two compares the control model with the adjustment model. Both designs require eighteen experiments to investigate all factor level combinations.

6.4.1. *Experiment One*

The simulation was run 150 000 hours with a warm-up period of 3000 hours to reach steady-state conditions. The data was then collected to evaluate the performance of the three due-date assignment rules. The performance measures are average flowtime, average lateness, standard deviation of lateness, average tardiness and % of tardy jobs.

The experiments were performed using 30 replications of each treatment. Tables 4 and 5 summarize the results of the eighteen experiments. The analysis of variance (ANOVA) (Tables 6 and 7) indicates that at a 0·05 significance level, all three sources of variation (release, scheduling rule and due-date assignment) and all two way

Scheduling rule	Due-date rules	Average flow time	Average lateness	Std. dev. lateness	Average tardiness	% tardy jobs
FIFS	NOP & TWK	64·40	7·29	35·81	32·56	49·73
	LIQ	61·95	2·33	22·16	17·26	50·79
	OITS	64·41	2·36	26·34	21·88	47·66
EDD	NOP & TWK	55·84	0·90	24·70	21·03	45·61
	LIQ	55·15	0·38	13·89	10·83	50·70
	OITS	50·93	- 0·48	16·07	12·24	46·96
T-SPT	NOP & TWK	43·71	0·42	33·76	30·53	38·27
	LIQ	43·61	- 0·12	25·13	17·39	46·45
	OITS	43·61	0·23	28·26	22·61	40·59

Table 4. Experimental results of basic model.

Scheduling rule	Due-date rules	Average flow time	Average lateness	Std. dev. lateness	Average tardiness	% tardy jobs
FIFS	NOP & TWK	51·47	1·72	18·55	15·39	51·24
	LIQ	51·47	1·32	16·19	13·05	51·45
	OITS	51·47	0·99	17·23	14·27	48·90
EDD	NOP & TWK	46·51	- 0·40	15·00	10·37	53·71
	LIQ	47·36	0·51	12·93	9·57	55·18
	OITS	45·64	- 0·50	13·02	9·18	51·65
T-SPT	NOP & TWK	31·73	- 0·43	17·86	16·69	38·80
	LIQ	31·73	- 1·88	17·08	12·81	39·48
	OITS	31·73	- 0·53	17·39	15·62	39·22

Table 5. Experimental results of control model.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Pr > F
Release model (A)	1	260·31	260·31	15·30	0·0001
Scheduling rules (B)	2	978·92	489·46	28·77	0·0001
Due-date assignment rules (C)	2	173·28	86·64	5·09	0·0064
A × B	2	118·83	59·42	3·49	0·0311
A × C	2	94·87	47·44	2·79	0·0624
B × C	4	195·60	48·90	2·87	0·0225
A × B × C	4	125·49	31·37	1·84	0·1190
Error	522	8879·28	17·01		

Table 6. ANOVA for average lateness.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	Pr > F
Release model (A)	1	10 899·93	10 899·93	723·89	0·0001
Scheduling rules (B)	2	4 978·52	2 989·26	198·53	0·0001
Due-date assignment rules (C)	2	3 895·19	1 947·60	129·35	0·0001
A × B	2	1 331·43	665·72	44·21	0·0001
A × C	2	2 060·07	1 030·04	68·41	0·0001
B × C	4	205·92	51·36	3·41	0·0091
A × B × C	4	58·92	14·73	0·98	0·4189
Error	522	7 859·93	15·06		

Table 7. ANOVA for standard deviation of lateness.

interactions (except A × C) are significant. This concludes that the performance of due-date assignment can be improved in a stable system which can be achieved by an appropriate order releasing method. Although A × C is not significant at a 0·05 significance level, its standard deviation of lateness is still quite significant.

The performance comparison for basic and control model was analysed by paired *t* tests, with those results listed in Table 8. This table reveals that for the standard deviation of lateness, the control model is markedly better than the basic model. This finding suggests that the control model increases the accuracy of the due-date assignment (or flowtime estimation). However, for the average lateness, except for the combination of T-SPT and LIQ, the control model is either better than the basic model or both are not significantly different. In contrast, for the % of tardy orders, except the combination of T-SPT and LIQ, the basic model is either better than the control model or both are not significantly different. However, if the control model uses the basic model's due-date rules' parameter value to estimate the interoperation time, the percentage of tardy orders will then be reduced significantly. This is because the interoperation time of the basic model is greater than that of the control model. For average tardiness and average flowtime, the control model is significantly better than the basic model.

Scheduling rule	Due-date rules	Average flow time	Average lateness	Std. dev. lateness	Average tardiness	% tardy jobs
FIFS	NOP & TWK	*(CONTROL)	*(CONTROL)	*(CONTROL)	*(CONTROL)	/
	LIQ	*(CONTROL)	**(CONTROL)	*(CONTROL)	*(CONTROL)	/
	OITS	*(CONTROL)	*(CONTROL)	*(CONTROL)	*(CONTROL)	/
EDD	NOP & TWK	*(CONTROL)	/	*(CONTROL)	*(CONTROL)	**(BASIC)
	LIQ	*(CONTROL)	/	*(CONTROL)	*(CONTROL)	*(BASIC)
	OITS	*(CONTROL)	/	*(CONTROL)	*(CONTROL)	**(BASIC)
T-SPT	NOP & TWK	*(CONTROL)	/	*(CONTROL)	*(CONTROL)	/
	LIQ	*(CONTROL)	**(BASIC)	*(CONTROL)	*(CONTROL)	*(CONTROL)
	OITS	*(CONTROL)	/	*(CONTROL)	*(CONTROL)	/

/ Not statistically different.
* Statistically different at significance level of 0·01
** Statistically different at significance level of 0·1.
( ) Model in parentheses is a better model.

Table 8. Performance comparisons for basic and control models.

Scheduling rule	Due-date rules	Average flow time	Average lateness	Std. dev. lateness	Average tardiness	% tardy jobs
FIFS	NOP & TWK	58·22	0·43	25·43	21·12	44·63
	LIQ	54·09	1·87	20·89	17·42	50·30
	OITS	60·62	− 3·63	24·28	17·81	40·38
EDD	NOP & TWK	49·48	− 3·36	15·50	9·72	44·50
	LIQ	51·04	0·10	13·98	9·58	52·97
	OITS	50·72	− 4·91	14·19	7·96	38·60
T-SPT	NOP & TWK	34·14	1·62	21·21	19·72	42·12
	LIQ	33·62	0·97	17·82	15·07	46·07
	OITS	35·09	1·08	19·19	17·95	42·35

Table 9. Experimental results of adjustment models.

6.4.2. *Experiment Two*

Experiment Two is the same as experiment one except that the basic model changes to the adjustment model in which the order release date is adjustable. Table 9 summarizes the results. Since the adjustment model only addresses the average tardiness and % of tardy orders, Table 10 provides only the performance comparison results for the control model and the adjustment model. Table 10 indicates that except for the combination of EDD and OITS, with respect to the performance of the average tardiness, the control model is significantly better than the adjustment model or both are not significantly different. However, for the percentage of tardy orders, the performance depends on scheduling rules. For FIFS and EDD, the adjustment model is better than the control model, since the adjustment model concentrates on due-date performance. However, combining with the T-SPT, the adjustment policy is disrupted, thereby making the control model better than the adjustment model.

Scheduling rule	Due-date rules	Average tardiness	Percent tardy jobs
FIFS	NOP & TWK	*(CONTROL)	*(ADJUST)
	LIQ	*(CONTROL)	/
	OITS	*(CONTROL)	*(ADJUST)
EDD	NOP & TWK	/	*(ADJUST)
	LIQ	/	/
	OITS	*(ADJUST)	*(ADJUST)
T-SPT	NOP & TWK	*(CONTROL)	**(CONTROL)
	LIQ	*(CONTROL)	*(CONTROL)
	OITS	*(CONTROL)	*(CONTROL)

/ Not statistically different.
* Statistically different at significance level of 0·01.
** Statistically different at significance level of 0·1
( ) Model in parentheses is a better model.

Table 10. Performance comparisons for control and adjustment models.

7. Conclusions

This study integrates the order releasing control method with due-date assignment rules. An order release control mechanism has been presented which aims to control manufacturing lead times. Several experimental designs are also performed to evaluate the effectiveness of integrating the due-date assignment. Based on the results in this study, we can conclude the following:

(1) Integrating of order release control with due-date assignment rules significantly improve the average flowtime estimation, due-date performance in average lateness and standard deviation of lateness.
(2) The integrated due-date assignment model, combined with the order release adjustment method, decreases the percentage of tardy orders when FIFS and EDD scheduling rules are used.
(3) Integrating order release control with due-date assignment rules reduces the number of shop floor information items in estimating the interoperation time. This subsequently increases the estimation accuracy of the interoperation time. However, the estimation accuracy of the interoperation time will increase the accuracy of the due-date assignment model.

Results in this study confirm the notion that integrating the order release control method with due-date assignment rules will significantly enhance the estimation accuracy of interoperation time and due-date performance of due-date assignment rules.

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