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PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

A production scheduling simulation model for improving production efficiency

Cheng-Liang Yang[1*] and Cheng-Chieh Hsieh[2]

Abstract: A real manufacturing system of an electronic company was mimicked by using a simulation model. The effects of dispatching rules and resources allocations on performance measures were explored. The results indicated that the dispatching rules of shortest processing time (SPT) and earliest due date are superior to the current rule of first in first out adopted by the company. A new combined rule, the smallest quotient of dividing shortest remaining processing time (SRPT) by SPT (SRPT/SPT_Min), has been proposed and demonstrated the best performance on mean tardiness time under the current resources situation. The results also showed that using fewer resources can increase their utilization, but it increases the risk of delivery tardiness as well, which in turn will damage the organization's reputation in the long run. Some suggestions for future work were presented.

Subjects: Manufacturing & Processing, Plant Engineering, Production Systems

Keywords: dispatching rule, system simulation, Arena, flow shop, resources allocation

1. Introduction

With the changes of information technology and strategy of global competitiveness, system simulation becomes a critical management tool for tackling the fast-changing environment (Cacciabue, 2011; Ramasesh, 1990; Wen & Yang, 2013). The most frequent problem manufacturing industry is facing is how to effectively use its limited resources in the production process. System simulation is often used to improve business processes and to solve the manufacturing problems. The scheduling problem in manufacturing systems has been explored for many years. This problem is a class of combinatorial problems known as NP-complete. Because of the difficulty of solving this problem directly, scheduling heuristics are often employed to simplify the problem. One of the most common classes of scheduling heuristics is dispatching rules (Caskey & Storch, 1996). These rules then can be simulated to determine which one will get the best performance in terms of production efficiency.

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PUBLIC INTEREST STATEMENT

Determining a proper production sequence among orders is a hard task for production engineers in manufacturing systems. The most common dispatching rule used in practice is FIFO. However, the current paper indicated that some rules are better than FIFO and can be considered by the engineers.

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There are considerable works of using dispatching rules to solve the production problems (Barrett & Kadipasaoglu, 1999; Blackstone, Phillips, & Hogg, 1982; Holthaus, 1997; Holthaus & Rajendran, 1997; Jayamohan & Rajendran, 2000; Karimi, 2009; Low, Kung, & Huang, 2010; Monch & Zimmermann, 2004; Reodecha & Werner, 2008; Wang & Jin, 2007; Wiem & Pierreval, 2010), but most of them utilized pseudo data to test their approaches. Thus, when the approaches are applied in a real manufacturing system, they cannot guarantee working well in practice, which will greatly decrease the feasibility and validity of these approaches. The current study therefore used Arena, simulation software, to develop a simulation model and used real data to mimic a real manufacturing system. Moreover, more practical situations, such as time for preparing materials and adjusting machines, were incorporated into the model.

Holthaus (1997) used a simulation method to explore the advantages and disadvantages of dispatching rules. Blackstone et al. (1982) and Haupt (1989) investigated different dispatching rules for manufacturing job shop operation. Barrett and Kadipasaoglu (1999) evaluated five static and four dynamic dispatching rules in a dynamic flow shop. The result indicated that shortest processing time (SPT) has better performance on mean flow time, mean lateness, and proportion of tardy jobs, but has counter-effectiveness on mean tardiness and lateness variance. In terms of tardiness and flow time, Holthaus and Rajendran(1997) compared SPT, first in first out (FIFO), and shortest remaining processing time (SRPT) with combined dispatching rules. The result showed that the combined rules are superior to the single rules. Based on the measure of tardiness, heterogeneous dispatching rules, i.e. allowing each machine to use its own rule, were employed in job and flow shops (Caskey & Storch, 1996). Some new dispatching rules to minimize rejection and tardiness costs were also presented (Karimi, 2009). In accordance with previous literature, single and combined dispatching rules with multi-performance measures were investigated in the current study. In short, the purposes of this study are (1) to explore the influences of the numbers of machines on resources utilization and performance measures, and (2) to investigate the effects of different dispatching rules on performance measures.

2. Problem description

In this study, a display production sub-system of an electronic company in Taiwan was modeled. The display sub-system is a classic flow shop production system. The jobs have to visit the stations in the same order starting from station one to the last station. This system contains six sequential stations: manufacturing, assembling, testing of basic rate interface, testing of ARI standard, inspection, and packaging. Basically, once the system receives a displays' production order, each display of the order will be viewed as an individual job. Each station has one machine or more than one machines, and each machine can only process one job each time. Thus, every station can accept a new production order only when all the jobs within the same order have been finished. This can prevent confusing the orders. Because the display type of each order is different, the machines at each station should be adjusted before processing new order. Meanwhile, each production order also needs time to prepare materials before producing displays. Owing to the short distance among stations, the delivery time from one station to another is omitted.

Seven dispatching rules are employed in our simulation model, that is, FIFO, LIFO (last in first out), earliest due date (EDD), SPT, SRPT, SRPT/SPT_Min (the smallest quotient of dividing SRPT by SPT), and SRPT/SPT_Max (the largest quotient of dividing SRPT by SPT). The current dispatching rule of the production system adopted is FIFO. Our objective is to present a better dispatching rule in terms of performance measures. These measures consist of mean completion time, mean flow time, mean waiting time, maximum flow time, mean tardiness time, maximum tardiness time, and mean order tardiness rate.

3. The scheme of the simulation model

The simulation model is divided into three stages: arrangement, assembling, and evaluation stages. In the arrangement stage, production orders are generated first, and then the orders data such as due date and production quantity are assigned. Materials for production are prepared and dispatching rules are chosen. Job orders are created in accordance with production orders and then go to the assembling stage.

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Figure 1. The scheme of the simulation model.
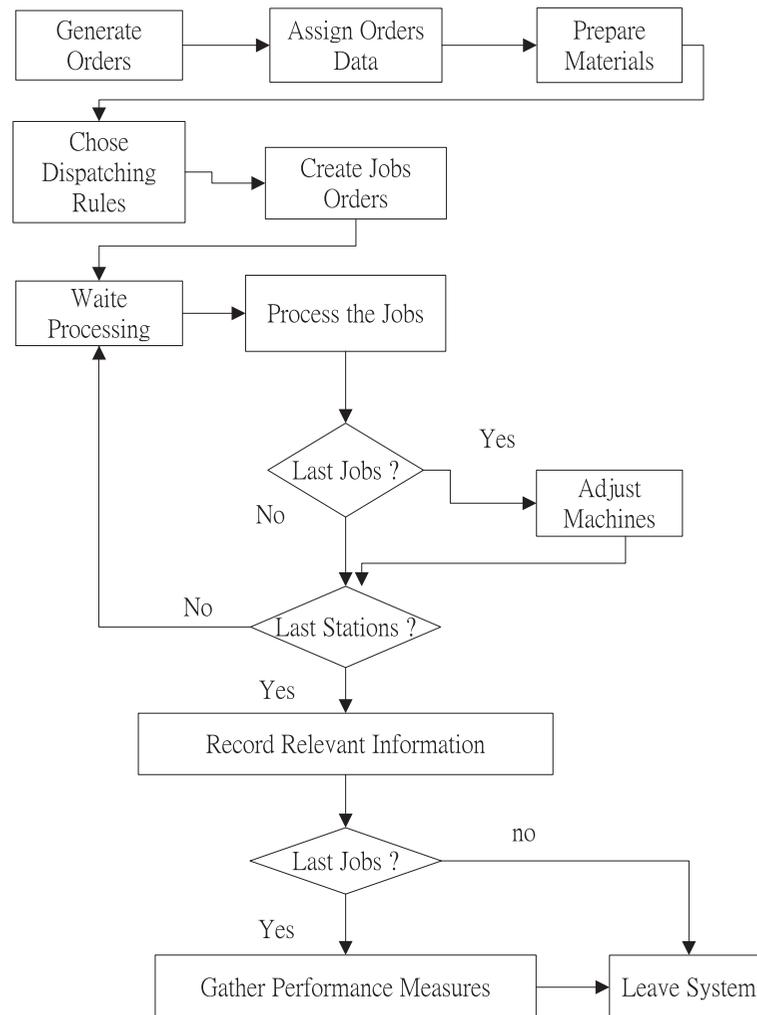
In the assembling stage, the jobs are waiting for processing. If the machines are available, the jobs arrive at the work station and are processed by utilizing the machines. After completing a job, we check whether the job is the last job of the production order at the station. If the job is the last job, the machines at the station are adjusted for next production order; otherwise, we go to check whether the station is the last station. If it is the last station, then the job leaves the station and goes to the evaluation stage; otherwise, it goes to the beginning of the assembling stage, i.e. waiting for processing, and continues its following steps.

In the evaluation stage, the job has been completed and relevant information, such as flow time and completion time, is recorded. Meanwhile, we also check whether the job is the last job of the production order at the last station. If it is, this production order has been completed and performance measures such as tardiness are gathered. If it is not the last job, the job will leave the simulation system and other jobs continue through the evaluation stage. The detail procedure of the model is presented in Figure 1.

4. Simulation design
The simulation model was designed by using the version 10 of Arena and simulated on the processor, Intel Pentium 1.8 GHz. Simulation data include interarrival time of production orders, operation time, due date, dispatching rules, and the number of machines.

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The time unit in this simulation model is hour based. There are 8 h per day for working, 5 working days per week, and 52 working weeks a year, and thus the total working hours per year are 2080 h. To ensure that the simulation environment is in a steady state, the warm-up time for the system was set up by 2080 h and the simulation time was set by 4160 h. To evaluate performance, we conducted two experiments and compared two kinds of machines allocations under seven dispatching rules. The first experiment was to simulate the different numbers of machines allocations to explore whether it was effective to reduce capacity idle, and the second experiment was to compare seven dispatching rules in terms of seven performance measures. The number of replication in each simulation experiment was set to 20. The parameters used in the model, such as orders interarrival time, operation time, machines adjusting time, number of jobs and so on, were estimated from the pratical data.

In this manufacturing system, there are 11 machines at Station 2, and only 1 machine at Station 3. The numbers of machines at Stations 4 and 5 are seven each, and have one more machine than those at Stations 1 and 6. The average operation time per job at Stations 1–6 are 1.167, 2.139, .194, 1.361, 1.361, and 1.167 h, respectively. The average operation time at Stations 4 and 5 are only a little bit longer than those at Stations 1 and 6. Therefore, it is interesting to know whether the numbers of machines at these two stations can be decreased to six each.

5. Simulation results

5.1. Different machines allocations
Using dispatching rule of FIFO, Table 1 presents the original machines allocations and their mean utilization of machines. Comparing the mean utilization of the original number of machines allocations, we find that there is no big difference among Stations 4, 5, 1, and 6. The average utilization is around .726.

By reducing one machine each at Stations 4 and 5, we can see that the mean utilization of machines greatly increases from .726 to .846 (see Table 2). This indicates that reducing machines

Table 1. The simulation result for original allocated machines			
Station	**The current machine allocations**	**Mean utilization of the machines**	**Mean order tardiness rate**
Station 1	6	.727	
Station 2	11	.727	
Station 3	1	.725	.5%
Station 4	7	.726	
Station 5	7	.726	
Station 6	6	.726	

Table 2. The simulation result for amended allocated machines			
Station	**The amended machine allocations**	**Mean utilization of the machines**	**Mean order tardiness rate**
Station 1	6	.719	
Station 2	11	.721	
Station 3	1	.719	5.43%
Station 4	6	.846	
Station 5	6	.846	
Station 6	6	.726	

can surely decrease capacity idle, but the mean order tardiness rate increases from .5 to 5.43%. Therefore, the mean order tardiness rate plays an important role when considering the problem of capacity idle.

The above experiment (Experiment 1) indicates that the decrease in machine allocations can surely reduce capacity idle, but it also increases the mean order tardiness rate. As a result, in the following experiment (Experiment 2), we continually explore different dispatching rules with different machines allocations and to see the effects on performance measures.

5.2. Different dispatching rules

From Tables 3 and 4, it is clear that all performance measures of the original machines allocations at each dispatching rule are superior to the amended machines allocations. The decrease in the number of machines can increase the utilization of resources, but particularly, it also increases the mean tardiness time, maximum tardiness time, and mean order tardiness rate. In practice, delivery tardiness may cause compensation for the violation of a contract. Thus, when considering the decrease in machines allocations to elevate the utilization, we must consider if it is able to save production cost or whether the cost cutting is higher than penalty for the violation. In addition, the loss of goodwill caused by delivery tardiness is another problem needed to be taken into account.

Under the original machines allocations condition, we compare dispatching rules with each other (see Table 3). SPT has more outstanding performances on mean completion time, mean flow time, maximum flow time, and mean waiting time than those in other dispatching rules. EDD has better performances on maximum tardiness and mean order tardiness rate. If we consider mean tardiness time, SRPT/SPT_Min is better than others.

Moreover, under the amended machines allocations condition (see Table 4), EDD has more outstanding performances on mean flow time, maximum flow time, mean waiting time, and maximum

Table 3. The dispatching rules with original machines allocations time unit (h)

Dispatching rule	Mean completion time	Mean flow time	Mean waiting time	Maximum flow time	Mean tardiness time	Maximum tardiness time	Mean order tardiness rate (%)
FIFO	80.21	35.86	28.46	87.95	−272.3	5.84	.50
LIFO	88.38	36.15	28.75	88.80	−267.4	223.91	2.32
EDD	83.24	36.20	28.80	89.28	−273.2	3.44	*.30*
SPT	*72.92*	*35.45*	*28.06*	*86.90*	−272.1	49.47	.93
SRPT	85.26	36.12	28.73	87.72	−275.9	122.14	1.23
SRPT/SPT_Min	73.99	35.71	28.32	88.93	*−276.8*	80.71	.88
SRPT/SPT_Max	94.59	36.44	31.44	89.81	−261.9	168.11	3.53

Table 4. The dispatching rules with amended machines allocations time unit (h)

Dispatching rule	Mean completion time	Mean flow time	Mean waiting time	Maximum flow time	Mean tardiness time	Maximum tardiness time	Mean order tardiness rate (%)
FIFO	156.6	89.7	82.3	156.6	−219.2	48.8	5.43
LIFO	162.6	95.0	87.6	160.8	−223.4	391.6	3.34
EDD	140.2	*81.1*	*73.7*	*138.1*	−228.6	*13.8*	3.40
SPT	140.5	89.3	81.9	154.6	−241.7	206.9	*2.55*
SRPT	*140.0*	88.4	81.0	149.8	−236.3	232.5	2.59
SRPT/SPT_Min	153.9	97.6	90.2	164.4	−223.9	338.5	2.77
SRPT/SPT_Max	227.7	97.1	89.7	162.2	−153.4	534.5	10.79

tardiness. However, SPT has better performances on mean order tardiness and mean order tardiness rate; SPRT has better performance on mean completion time.

In summary, the results in the original and amended machines allocations are different, but basically, the rules of SPT and EDD are the first two best choices of the seven dispatching rules. Particularly, as resources are scare and penalty of exceeding due date is high, SPT could be better than EDD (2.55–3.40% of mean order tardiness rate). On the contrary, under the current resources situation, EDD is better than SPT (.30–.93%). Considering the measure of tardiness time, which is defined as the order's completion time minus the order's due date, its negative sign means that the order is completed before its due date. If there is a premium for early delivery orders, the new combined dispatching rule presented by our paper, SRPT/SPT_Min, is the best choice at the original machines allocations condition (the average of being ahead of due date is 276.8 h).

6. Conclusions and future work

Instead of using pseudo data to test approaches, data from a real manufacturing system of an electronic company were adopted in this study. We constructed a practical simulation model to investigate the effects of dispatching rules and resources allocations on performance measures. The results showed that using fewer resources can increase their utilization, but it also increases the risk of delivery tardiness, which in turn will damage the company's reputation. Therefore, we suggest that the company maintains the current number of machines allocations. For the determination of dispatching rules, a new proposed rule, SRPT/SPT_Min, has demonstrated the best performance on mean tardiness time under the current situation. The results also indicated that the rules of SPT and EDD are superior to the current rule of FIFO. Under the current resources situation, we suggest that the company adopts EDD rather than FIFO.

Although this study has put great efforts into different approaches, there are still some factors not taken into consideration. For example, to simplify problems, factors such as machine maintenance or machine breakdown, which could really happen in practice and may lead to an interruption of the working process, are not taken into account. Thus, these factors should be explored further to make the results more practical.

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