A Scheduling Method for Painting Line under Pull Production*

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This paper concerns with a scheduling method for painting (preceding) line with much longer production lead-time than assembly (subsequent) line. In general, production schedule of the painting line is made independently based on the forecasted job requirement at the assembly line. When the job requirement changes at the assembly line by virtue of the change of customer order, therefore, production balance is destroyed between the both lines. To avoid the tardiness caused by such unbalance, we need to have many inventories for the painting line. Such countermeasure is taken place in many companies actually. Thus, to avoid the tardiness while keeping small inventory, we propose a scheduling method that makes a Pseudo-Pull production possible for the painting line. We have evaluated the proposed method through computer simulations.

Key Words: Painting Line, Make-to-Stock Production, Pull Production, Pseudo-Pull Production, Scheduling Method

1. Introduction

Generally, it is difficult to keep a proper production corresponding to the demand when production lead-time of painting (preceding) line is much longer than its assembly (subsequent) line. Under such production environment, MTS (make-to-stock) production[2] is usually applied in the painting line. In MTS production, products are to be produced based on demand forecasts rather than actual orders from customer. However, when unpredicted changes happen in the assembly line by virtue of the change of customer order, the MTS production cannot cope with such changes, and delay occurs likely against the production demands. Therefore, large WIP (work-in-process) inventory becomes necessary for the painting line to fulfill promptly the production demand of the assembly line.

Associated with such production of the painting line, Nagamoto et al.[5] proposed a method to achieve simultaneously lot production for painting line and production smoothing for assembly line by the installation of two painting lines. However, as a drawback, this approach raises the equipment cost in terms of the additional installation.

Monden[1] introduced the individual sequencing method for the painting line and the assembly line to correct the sequence disturbed by wastrels in the painting line (see Fig. 1). This method requries the storage facility that adjusts the sequence of job injection at the assembly line. However, it is apparent this method cannot deal with the change of the customer order because it is based on the production smoothing regarding the usage of parts at the assembly line.

From the above statements, simultaneous reductions of the WIP inventory and the tardiness are essential to achieve a rational production in the painting line. For this purpose, in this paper, we try to build a Pseudo-Pull production between the painting line and the assembly line. The Pull production known as JIT production system can achieve the efficient production with a little WIP inventory[3],[4]. However, it is difficult to apply directly the Pull production in the present case because the prompt production is impossible against the production demands due to longer production lead-time at the painting line.

Hence, we propose a scheduling method that enables us to build a Pull production imitatively at the painting line (Psuedo-Pull production). The effectiveness of the proposed method is verified by some

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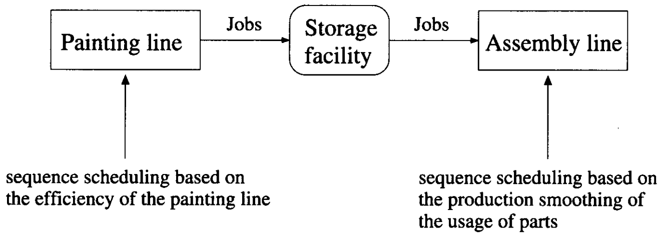

Fig. 1 Scheme of the sequencing method by Monden

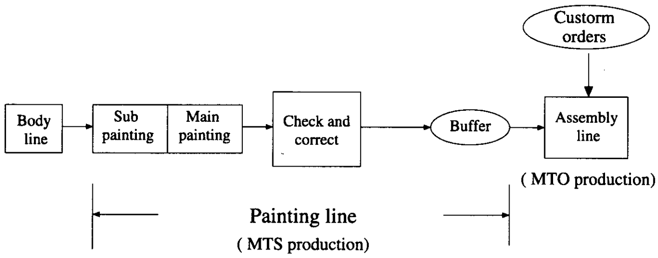

Fig. 2 Scheme of the painting line model

numerical experiments.

This paper is organized as follows. In section 2, we develop a model for the painting line and the assembly line. In section 3, we propose a scheduling method to realize Psuedo-Pull production. Section 4 is devoted to the numerical examples.

2. Model of Painting Line

The following conditions are assumed in the modeling of the painting line and the assembly line as shown in Fig. 1.

[Assumption]

(1) Painting line is composed of consecutive conveyor lines.

(2) Multi-product is classified by the difference of painting color.

(3) There are two operation types for painting, i.e. once and twice painting. Hereinafter these are called painting job and re-painting job respectively.

(4) In the painting line, defective jobs about painting color exist.

(5) The assembly line is subject to the smoothing production and as well as MTO (make-to-order) production based on customer order.

(6) There exists a buffer as the WIP inventory between the painting line and the assembly line.

(7) Change of customer order is generated every production period.

The painting line is operated in the order of sub-painting, main painting and check processes (see Fig. 2). The re-painting jobs pass through main painting process twice. Defective jobs are to be sent to the buffer after correction. The job sequencing of the assembly line is reviewed at every production

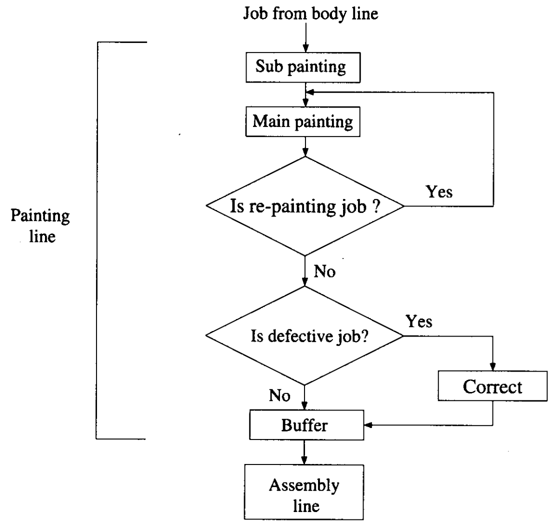

Fig. 3 Job flow in painting line

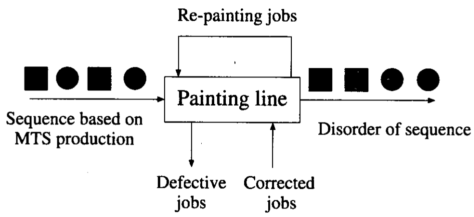

Fig. 4 Changed job sequence incurred the painting line deviation

period. From buffer, a necessary job is subtracted corresponding to the production sequence of the assembly line (see Fig. 3).

3. Scheduling Method for Painting Line

When the MTS production is used at the painting line, the sequence of the completed job may be different from the scheduled sequence due to the existence of defective and re-painting jobs (see Fig. 4). Because the completed job is different from the actual production demand at the assembly line, such production environment will arise problems regarding due date and WIP inventory. In other words, tardiness and earliness may occur due to the unpredicted changes of customer order. To reduce such deviation, schedule at the painting line must correspond promptly to the changes of the customer order at every production period.

Below, we propose a scheduling method that enable us to keep Pseudo-Pull production between the painting line and the assembly line with small WIP inventory and without tardiness. However, the production efficiency deteriorates when improper Pull production is used between the two lines whose production lead-time is quite different. From this recognition about the inefficiency, we pay attention to buffer put between the painting line and the assembly line. By examining the type of the jobs in the buffer, the painting line can recognize the jobs required at the assembly line. Making a schedule regarding the sequence based on thus obtained information, we can realize a Pseudo-Pull production between the painting line and the assembly line. Moreover, the proposed scheduling method can cope with the change in the customer order to revise the schedules, based on the job number of the buffer in every production period.

The procedure of the proposed scheduling method is shown in the following (see Fig. 5).

[Scheduling method]

Step 1: Prepare an initial schedule and the quantity of WIP inventory at the painting line so that tardiness will not occur against the changes in the production number and sequence of the assembly line. Then, calculate the number of each job type from the WIP inventories. We call the number of each job type *standard value* for the initial schedule.

Step 2: Examine the number of each job type from the WIP inventories at each production period, and adjust the number of jobs necessary to maintain the nominal condition. That is, at the production period $i+1$, the number increases by C_j-B_{ij} if $B_{ij}\leqq C_j$ whereas decreases by $B_{ij}-C_j$ if $B_{ij}>C_j$. Here B_{ij} denotes the number of WIP inventory of the job j $(=1, \cdots, J)$ at the production period i $(=1, \cdots, T)$, and C_j the number of job j in the *standard value*.

Step 3: Modify the sequence of the initial schedule according to the changed number of each job. This is done by replacing the job at excess inventory with one at short inventory in turn under the following priority.

[Priority from the top to the bottom]

1) Re-painting job

2) The job with the smallest WIP inventory at the current production period

3) The job with large production demands

Thus modified schedule is used at the next production period.

Step 4: Repeat Step 2, 3 during the production planning period.

Hereinafter, we call Step 2 and Step 3 the revised scheduling.

The above procedure requires to decide the initial schedule in Step 1. Here, we use the following method to find such an initial schedule.

[Method using LS (Local Search)]

Step 1: Create an arbitrary schedule S. Consulting with the past sequences FS of the assembly line (assumed given a priori), decide the quantity of WIP inventory B. This is done by examining the number of necessary job types not to occur tardiness under FS. Hereinafter, we call B buffer size. And, let $m:=1$, $S^*:=S$ and $B^*:=B$.

Step 2: If $m=M$, go to Step 5. Here, $M(>0)$ denotes a parameter value to finish this algorithm.

Step 3: Derive the neighborhood[*1] of S, S', and decide B in the same way as the Step 1 for S'.

Step 4: If only $B<B^*$, make $S^*:=S'$ and $B^*:=B$. And let $m:=m+1$, $S:=S'$ and go to Step 2.

Step 5: Substitute S^* and B^* for an initial schedule and the quantity of WIP inventory respectively, and then stop.

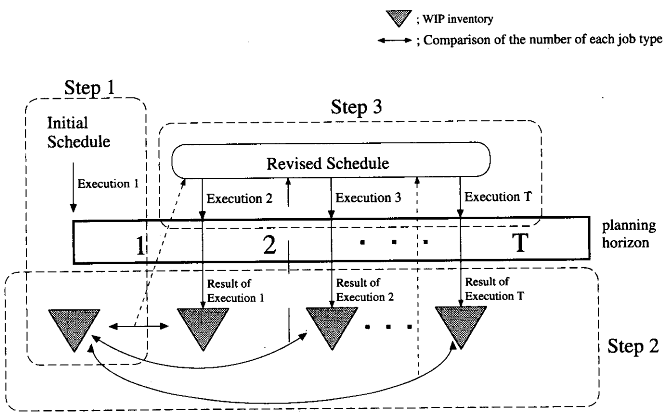

Fig. 5 A Scheme of Proposed Scheduling Method

4. Numerical Experiments

Numerical experiments are taken place under the following conditions: the planning horizon is 10 days; production time is 480 minutes per day; the total job number is 100. Furthermore, Table 1 shows the numbers of job and production times of each job. We also assumed that the job number suffering the sequence change in the assembly line is 4% of the total job number during the production period. Moreover, every production period, the production number is supposed to change within 2% with the probability of 50%. And we evaluated the effectiveness of the proposed method by using the average from 100 data sets. We also assumed that, at the planning stage, we have certain WIP inventories in the buffer, and jobs on the painting line were arranged beforehand.

Table 1 The numbers of jobs and production times

	Job A	Job B	Job C	Production time[min]
Painting job	24	26	30	480
Re-painting job	10	7	3	720

[*1] The insertion neighborhood[(8)] is used.

4.1 Comparison with the previous method[9]

At first, to examine the effectiveness of the proposed method, we compared the necessary buffer size and the average earliness underlying no tardiness with the previous method in Table 2. The previous method generates the initial schedule just through the production smoothing (see Fig. 6). From it, the proposed method is known to realize the efficient production, i.e. smaller WIP inventory and less earliness as well compared with the previous method.

4.2 Effect of revised scheduling

Next, we examined the effect of revised scheduling, i.e. Step 2 and Step 3 of the proposed method. Figure 3 shows tardiness and earliness of each job when the initial schedule decided at Step 1 is taken over the whole production period without revision against the changes in the production number and sequence of the assembly line (*initial method*). This production is correspond equivalently to MTS production. There appears the tardiness many times over the whole period of the production plan. This shows that the initial schedule cannot cope with the change of production at the assembly line effectively (see Fig. 7).

Figure 8 shows the tardiness and the earliness of the proposed (revised) scheduling. In contrast to the earlier case, the tardiness job hardly occurs. This shows that the revised scheduling enables us to absorb the production changes in the assembly line.

Table 3 shows the necessary buffer size and the average earliness under the condition that the tardiness must not occur by the initial scheduling and the revised scheduling. This result shows that the proposed scheduling method is efficient both from the aspect of the buffer size and the earliness.

4.3 Consideration on changes of production environment

To evaluate flexibility against the changes of the defective rate of job in the painting operation and the customer order, we compared the tardiness in Figs. 9 and 10. Figure 9 shows the tardiness for the change of defective rate in the painting line assuming change rate of the customer order at 5% to the whole production job number. Here the defective rate means the ratio of defective job number to the whole production job number. By the *initial method*, the tardiness increases to the defective rate while it is nearly constant, and less than that of the *initial method*. This come from the frequent re-scheduling during the production planning horizon.

Moreover, we compared the effect on the tardiness by the change rate of the customer order. In this case, the defective rate is assumed constant at 20% of the whole production job number. As shown in Fig. 10,

Table 2 Comparison of buffer sizes and average earliness between two methods

	Previous method	This work
Buffer size	41	37
Average earliness	107.1	102.1

Sequence = A b c a B c a b C . . .

A, B, C : re-painting job types a, b, c : painting job types

Fig. 6 A injection sequence based on the production smoothing

Table 3 Buffer sizes and average earliness by the initial scheduling and the proposed scheduling

	Initial scheduling	Proposed scheduling
Buffer size	60	51
Average earliness[min]	233.3	192.1

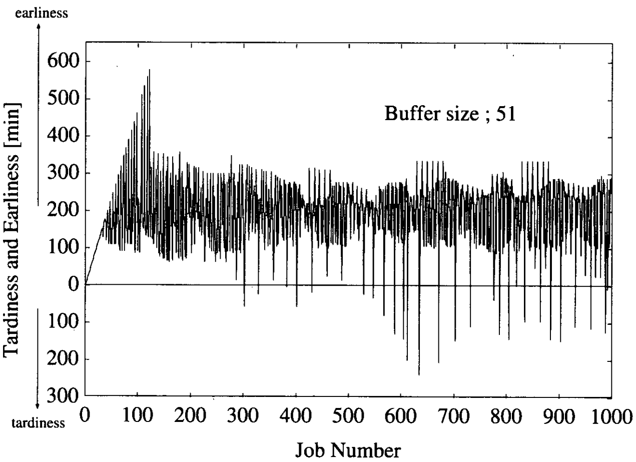

Fig. 7 Tardiness and earliness applied only initial scheduling

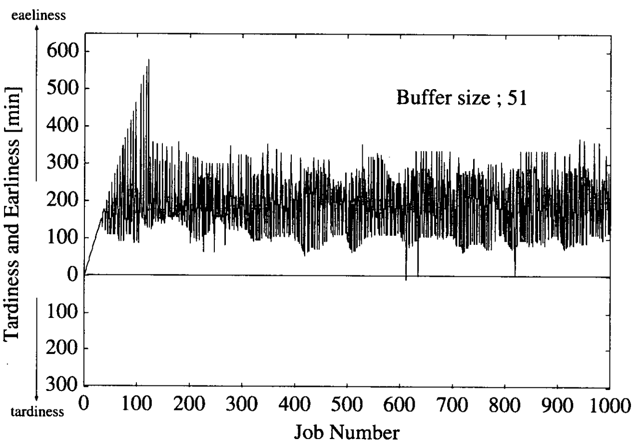

Fig. 8 Tardiness and earliness of the proposed scheduling

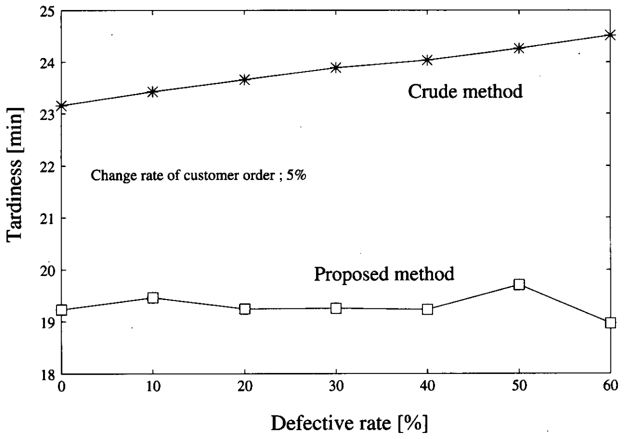

Fig. 9 Tardiness against the defective rate

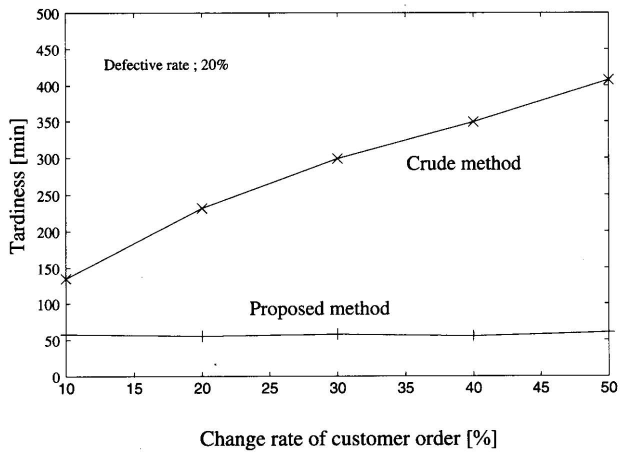

Fig. 10 Tardiness against the change rate of customer order

the tardiness of the proposed method is almost constant against the change rate of the customer order, and much smaller compared with that the *initial method*. This come from the re-scheduling associated with the condition of job type in the buffer.

If we would apply the method of Monden (see Fig. 1) in this case, the tardiness might increase to the change rate of customer order. This in because sequence scheduling is taken place based on the indivial aim both the at the painting and the assembly lines.

From these results, we can recognize that the proposed method is more efficient than MTS. After all, the Pseudo-Pull production mentioned here is realized by reviewing the properties of job in the buffer every production period, giving its information to the painting line production, and making the scheduling based on it, i.e. based on the inverse or pull information. It has advantages over MTS production from the aspects of due date requirement and inventory cost. The above numerical experiments have shown such statements.

5. Conclusion

In this paper, we concerned with the production system where each lead-time is quite different between the adjacent processes (a painting line based on MTS production and an assembly line based on MTO production). To realize the Pseudo-Pull production between them, we proposed a scheduling method that cannot only reduce the WIP inventory but also meet the due date condition. This is why the proposed scheduling enable the painting line to recognize the job type required at the assembly line, and to make a schedule regarding the sequence based on thus obtained information. In addition, the proposed method can cope with inefficiency caused by change rate of customer order by improving the schedule in every production period. By simulation, we have shown the effectiveness of the proposed method.

References

(1) Monden, Y., Toyota Production System: An Integrated Approach to Just-In-Time, (1991), Industrial Engineering and Management Press, Atlanta.

(2) Balakrishnam, A., Frarcis, R.L. and Grotzimger, S.J., Bottlerneck Resesource Allocation in Manufacturing: Management Science, Vol. 42, No. 11 (1996), pp. 1611-1625.

(3) Golhar, D.Y. and Stamm, C.L., The Just-In-Time Philosophy: A Literature Review, Internat. J. Production Res., Vol. 29 (1991), pp. 233-247.

(4) Kubiak, W., Minimizing Variation of Production Rates in Just-in-Time Systems: A Survey, European J. Oper. Res., Vol. 66 (1993), pp. 259-271.

(5) Nagamoto, M. and Morito, S., Sequence Scheduling with Grouping and Smoothing Consideration, Proceedings of the Production Scheduling Symposium '98, (in Japanese), (1998), pp. 29-34.

(6) Andreas, D. and Alf, K., Sequencing JIT Mixed-Model Assembly Lines under Station-Load and Part-Usage Constraints: Management Science, Vol. 47, No. 3 (2001), pp. 480-491.

(7) Inman, R.R. and Bulfin, R.L., Sequencing JIT Mixed-Model Assembly Lines: Management Science, Vol. 37 (1991), pp. 901-904.

(8) Aarts, E.H.L. and Lenstra, J.K., Lacal Scarch Algorithms, (1997), John Wiley and Sons Ltd.

(9) Yoo, J.K., Hatono, I., Tomiyama, S., Tamura, H., A Method of Keeping Smoothed Production in JIT Production Systems with Machine Breakdowns, Proceedings of the Production Scheduling Symposium '97, (in Japanese), (1997), pp. 49-54.