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SYSTEM ANALYSIS OF A MULTI-PRODUCT, SMALL-LOT-SIZED PRODUCTION BY SIMULATION: A KOREAN MOTOR FACTORY CASE

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Abstract—In this article, a simulation model of an existing motor production line is developed to identify system parameters to improve the system performances such as facility utilization, flow time, and buffer sizes (work-in-process inventories). System parameters investigated include dispatching rules, setup time reduction, overwork, demand increase, and productivity improvement. The simulation results have been applied to the development of a new layout. The model has been developed using SIMAN simulation language which has been demonstrated to be a powerful tool to simulate complex manufacturing systems. Copyright © 1996 Elsevier Science Ltd

1. INTRODUCTION

Simulation has been used extensively to design new manufacturing systems and to improve the performance of existing systems. In the design and operation of manufacturing systems, simulation is often used prior to the operation of the real system as a mediator for dynamic analysis [1]. The purpose of this article is to investigate the effect of parameters for system performances on a Korea motor production factory which has multi-product (about 1200 items), small-lot-sized (from several tens to hundreds) production characteristics. The system performances have been measured as facility utilization, flow time, and buffer sizes (work-in-process inventories). System parameters investigated include dispatching rules, setup time reduction, overwork, demand increase, and productivity improvement. The current layout of the factory has been shown to possess several problems including long flow times, large work-in-process inventories, several bottleneck operations, etc. The simulation results have also been applied to the development of an improved layout. We simulate and study a stator core production line and an automatic varnishing operation which are parts of the motor production line.

The type of machining facilities, standard operation times, and the number of workers required to develop simulation models are fully reflected and production planning data are used as input data to the model. Also, the operation rules developed from empirical experiences of shop engineers are considered. Procedures for this study are as follows.

① Development of a conceptual simulation modeling: a conceptual model which emphasizes material flows of the factory has been developed. By analyzing actual production line we developed a basic model, and defined components, system parameters, and logic of the model.

② Basic data collection and analysis: basic data and line operation rules such as production plans for each model, routing (including alternative routing) of each model, setup times, production quantities, assembly due date, facility and line control rule, standard time, speed of trolley conveyors for automatic varnishing facility, have been analyzed using the field data.

③ Development of a simulation model: we have developed a simulation model using the proposed basic data, and performed experiments under various conditions.

④ Selection of an optimal layout: we have analyzed simulation results for the increasing demand data for five years from now. The system performances are measured by facility utilization, flow time, and buffer sizes. The effects of setup time reduction, productivity improvement, increasing demand on the system performance have been investigated.

In order to perform this study according to the above procedures, we used SIMAN simulation language which has been demonstrated to be a powerful tool to simulate complex manufacturing systems [2].

2. SYSTEM DESCRIPTION AND MODELING

2.1. Process analysis

Defining the system's boundary is necessary for simulation modeling, and definitions of product flows between facilities or operations, part routings, and setup requirements are made. Therefore, we drew up an operation chart of the production line to ease the process analysis (see Fig. 1). Several control rules have been employed to balance work loads. Routing ①. in Fig. 1 can be applied to a batch with a small group number from 1–9 or from 10–26. If a batch (lot size smaller than 200) arrives and the winding machine A is busy, it can be routed to winding machine B in case that machine is idle. Routing ②. in Fig. 1 can be applied to a batch with a small group number from 20–26. If a batch (lot size smaller than 200) arrives and winding machine A is busy, it can be routed to winding machine C in case the machine is idle.

The actual lines are modeled as follows:

A. Automatic line (including automatic varnishing) for small-sized motors

① This line consists of four operations: inspection operation → inserting operation of insulating paper → winding operation → forming section 1 (with eleven suboperations).

② The number of workers: fourteen workers are assigned to this line (two workers are assigned to a suboperation and one worker to each other operation).

③ Operations which require setup are inspection operation, inserting operation of insulating paper, winding operation, and first suboperation of forming Section 1.

B. Manual line for small-sized motors

① This line consists of three operations: inserting operation of insulating paper → winding operation → forming Section 2 (with eleven suboperations).

② The number of workers: fourteen workers are assigned to this line (three workers are assigned to a suboperation of forming Section 2 and one worker is assigned to each other operation).

③ Operations which require setup are inserting operation of insulating paper, winding operation, and first suboperation of forming Section 2.

2.2. Input data

We collected basic data for the system operations such as production planning, operation sequences, operation times, line control rules, etc. In some cases, we simplified the complicated situations. For example, sequence-dependent setup times are simplified as sequence-independent setup times, and defective rate and breakdown rate of special facilities are combined as a parameter because the shop has kept data on the performance of the production line in the form of loss rates.

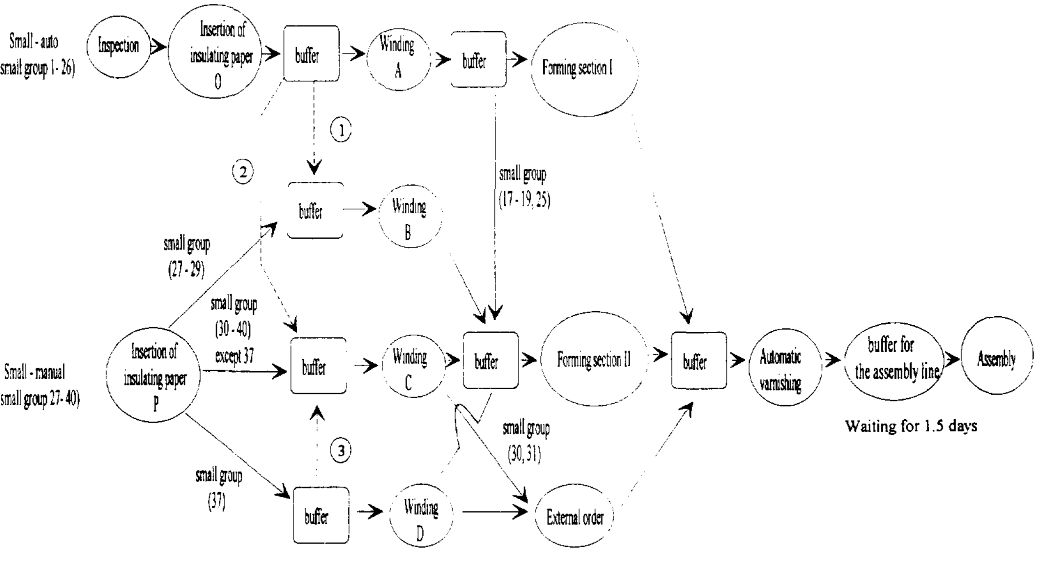


Fig. 1. Operation chart of the motor production line.

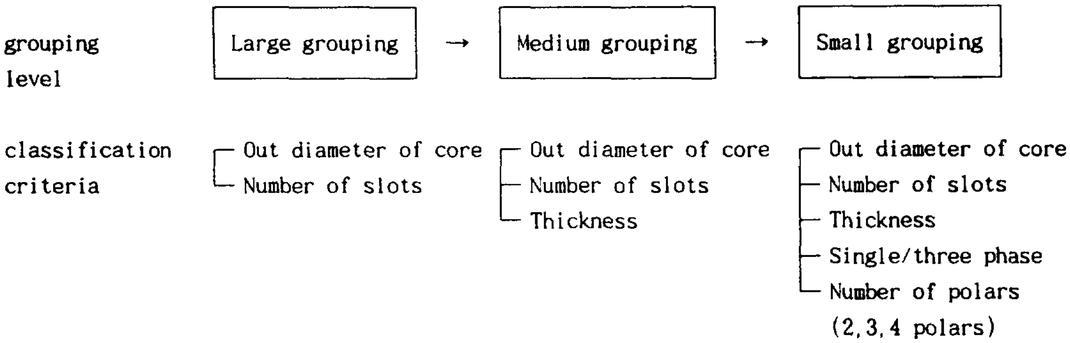


Fig. 2. Grouping of product models.

The three major sources of loss are setup operations, defective items, and machine breakdowns. We extracted setup times from loss rates, and considered them separately in the modeling. However, the remaining two parameters cannot be separated since we couldn't obtain the individual data. If the machine breakdown rate is negligible, as in this manufacturing shop, it doesn't hurt too much by combining two parameters.

It was difficult, if not impossible, to use current coding systems in the simulation modeling due to product diversification. Consequently, all kinds of products are classified and have unique large group, medium group, and small group numbers as in Fig. 2, and a new coding system with three parts has been developed. Because processing flows of each model are different, we group product models according to a grouping rule shown in Fig. 2, assign new product model number according to its routing in the simulation model.

We used two sets of production planning data obtained from the factory. The first was a production plan from August to October (which was a peak period) last year (we call this year 0), and the second is forecasted demand data for five years from now (year 1). The reason that we use the past data is to validate the simulation model by comparing simulation output and actual system output. The data used in this article have been altered slightly in order to protect the company's security. The input data of the production plan are composed of three parts; large group numbers and batch size, medium and small group numbers, and operation information numbers which are designated in the production plan, the number of setups required, and due date for assembly. In addition, after finishing production of a certain model, setups such as changing jigs and fixtures are required and setup times should be considered. In our model, setup times have been explicitly included because setup operations affect the system performances greatly. Setup operations occur according to four factors; large group, medium group, small group, and detailed model numbers in small group.

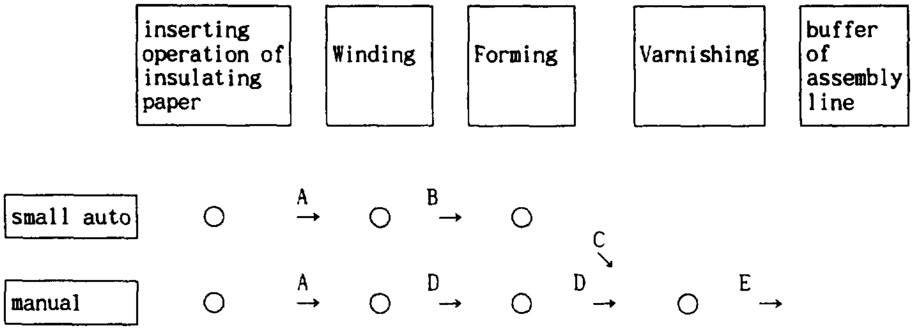
Buffer sizes are measured in terms of number of flatcars since cores are loaded into flatcars, and they are stored at buffers in flatcars. Flatcars are also used to move cores between operations and their types and sizes are different for each operation (Fig. 3).

We need to measure the core sizes in order to compute the number of cores to be loaded to a flatcar. The core which flows through the production line has different sizes by product model, before and after winding operation. Therefore, different core sizes are considered in the simulation model before and after winding operation. The core size is determined mainly by the medium group number. Core sizes after winding operation and forming operation become smaller, but the difference is small enough to be ignored in this study.

Inserting operation of insulating paper and winding operation are running at two shifts (total 1180 min per day) and other operations are running at one shift (580 min). Auto varnishing operation is running at two shifts (1180 min).

2.3. Simulation modeling

A product model can be processed with various process sequences. For example, if a product model arrives at a facility but it is busy and an alternative facility is idle, then the product model is sent to the alternative facility and processed. Simulation model is explained by the operation



(a) Types of flatcars

flatcar A : 18820 flatcar C : 33920 flatcar E : 35780
flatcar B : 25000 flatcar D : 36720

(b) Sizes of flatcars (unit: ㎠)

Fig. 3. Types and sizes of flatcars.

chart in which modules and relations between them are described. The simulation model consists of ten modules (Table 1), and is developed using SIMAN simulation language. Examples of SIMAN modules are shown in Fig. 4.

3. SIMULATION RESULTS

We simulate six different experiments using production planning data of a peak period for year 0. The run length is 3 months, and 5 days have been used as a warm-up period. Each experiment

Table 1. Modules of simulation model

Module name	Description of module
Input data module	Read production plan data. Decide the routing according to the model number.
Auto inspection operation module	Identify group number of the entity. Check whether a setup is required or not. After inspection, send the entity to the automatic insulating paper inserter.
Auto insulating paper inserting operation module	After insulating paper inserting operation, insulating paper of cores are loaded into a flatcar. If they can be processed by a manual winding machine, then they are sent to the winding operation. Or else, they are sent to the automatic winding operation.
Auto winding operation module	Check whether a setup is required or not by identifying the group number. After winding operation, cores are loaded into a flatcar to be sent to a queue in front of forming section I.
Forming section I	After forming operation, cores are sent to the auto varnishing facility.
Manual insulating paper inserting operation module	Check whether a setup is required or not by identifying the group number. After inserting operation of insulating paper, cores are loaded into a flatcar. After identifying the routing, cores are sent to the manual winding facilities B, C, and D.
Manual winding operation module	If there are no cores in the queues for the manual winding facilities B and C, then the queue in front of the automatic winding facility is checked whether there is any core which can be brought to the manual winding facilities. After winding operation, cores are loaded into a flatcars to be sent to a queue in front of forming section I.
Forming section II	After forming operation, cores are sent to the auto varnishing facility.
Auto varnishing operation module	Load cores on to the trolley to perform a varnishing operation. Cores are sent to a buffer for the assembly line after the operation.
Buffer for the assembly line	After varnishing operation, collect statistics on the number of flatcars that are stored in the buffer for the assembly line.

is simulated with ten replications. Experimental parameters and output to be evaluated are summarized in Fig. 5. The system performances are measured by facility utilization, flow time, and buffer sizes (work-in-process inventories).

```
  ==================================
  Auto varnish station
  ==================================

Avarnish  split;
          queue,varnish_q;
          scan:NR(basket)==0.and.NQ(velt_q2)==0
          .and.nq(pnu64)==0 .and.nr(dummy)==0;
a10       queue,pnu64;
          seize:dummy;
          assign:n10_2=n10_2+1;
                n10_3=n10_3+1;
          branch,2:
          if,n10_3==amod(a(1),1000)b10:
          if,n10_3.ne.amod(a(1),1000).and.
          n10_2==aint(capa(is)/core_size(amod(a(2),100)))+1,c10:
          if,n10_3.ne.amod(a(1),1000) .and.
          n10_2.ne.aint(capa(is)/core_size(amod(a(2),100)))+1,a10:
          always,d10;
b10       assign:n10_2=0:
                n10_3=0:dispose;
c10       assign:n10_2=0:dispose;
d10       tally.inavsta.int(arrtime);
          assign:M=40;
          delay: 0.001;
          release: dummy;
          assign:n10_4=n10_4+1:
                n10_5=n10_5+1:
                is=4;
          branch,2:
          if,n10_4==1,g10:
          always,h10;
h10       branch,1:
          if,n10_5==amod(a(1),1000),f10:
          if,n10_4==com(aint(a(1)/1000)),e10;
e10       signal:10;
          assign:n10_4=0:dispose;
f10       signal:10;
          assign:n10_5=0:
                n10_4=0:dispose;
g10       queue,velt_ql;
          wait:10;
          queue,velt_q2;
          seize:basket;
          DELAY:trolleyint;
          release: basket;
          QUEUE,velt_q3;
          ACCESS:trolley,1;
          CONVEY:trolley,41;
```

Fig. 4. Example of SIMAN codes for auto varnishing operation module.

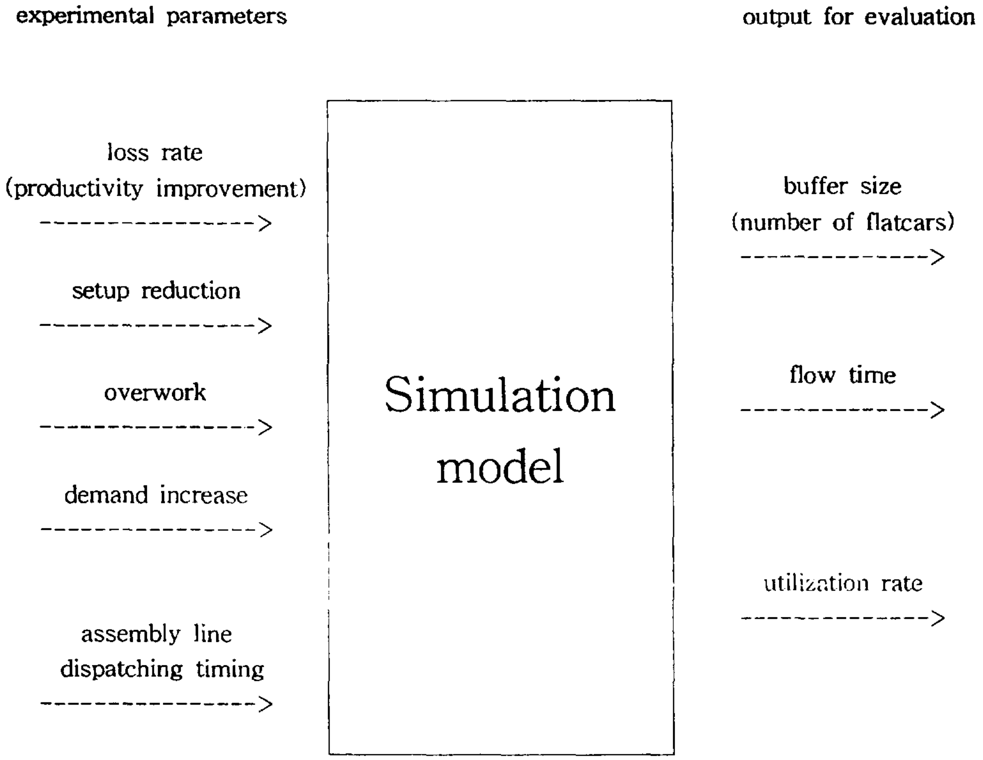


Fig. 5. Experimental parameters and performance measures.

3.1. *Dispatching timing*

In a typical batch processing environment, there are several factors that have critical impact on system performances. For example, dispatching rules are usually adopted as a means to resolve queue priorities when queues are encountered. An appropriate dispatching rule, which may be highly system specific, can result in a lower flow time, better machine utilization, and lower work-in-process inventories [3]. One of the factors affecting the system performances of this shop is dispatching timing after cores arrive at the buffer in front of the assembly line. The results show that the buffer size in front of the assembly line is minimized when the cores, after the auto varnishing operation, are sent to the assembly line after delaying 1.5 days at its buffer. The mean

Table 2. Effect of dispatching timing and overwork

Average number of flatcars (unit: unit)		Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6
Auto	Core stock	2.0	2.0	2.0	2.0	2.0	2.1
	After winding	3.8	3.8	3.8	3.8	3.8	2.5
Manual	Core stock	3.3	3.3	3.3	3.3	3.3	3.3
	After winding	3.3	3.3	3.3	3.3	3.3	2.3
After forming		4.0	4.0	4.0	4.0	3.8	3.7
Subtotal		18.7	18.7	18.7	18.7	18.5	15.7
Buffer for the assembly line		20.6	18.0	17.8	23.7	20.7	24.6
Total		39.3	36.7	36.5	42.4	39.2	40.3
Flow time (unit: min)	After forming section I	3129	3130	3131	3131	3130	2532
	After forming section II	2865	2867	2864	2867	2865	2635
	After vanishing	3979	3978	3980	3978	3949	3456
	Before assembly	6229	5944	5960	6682	6213	6137

- Description of experimental conditions.

Exp 1. Basic conditions and production plan in a peak period (year 0).

Exp 2. If the core arrives at the buffer before the assembly due date then the due date is decreased by 0.5 day. Or else send cores to the assembly line after 0.5 day.

Exp 3. Send the cores to the buffer for the assembly line 1.5 days after they arrive.

Exp 4. Send the cores to the buffer for the assembly line 2 days after they arrive.

Exp 5. Run the auto vanishing operation 24 h a day.

Exp 6. Extend the working time of forming section II from 580 min to 640 min.

Table 3. Effect (in terms of utilization rates) of dispatching timing and overwork (unit: %)

		Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6
Auto	Winding	95.9	95.9	95.8	95.9	95.8	95.9
	Forming section I	96.3	96.3	96.4	96.3	96.4	88.0
Manual	Winding machine B	53.8	53.8	53.8	53.8	53.8	53.8
	Winding machine C	74.3	74.3	73.5	74.3	73.6	73.6
	Winding machine D	95.4	95.4	96.4	95.4	96.4	96.4
	Forming section II	94.3	94.3	94.3	94.3	94.3	85.7
Auto varnishing*		60.8/90	60.8/90	60.9/90	60.8/90	49.9/90	63.7/90

*Average number of hangers with cores.

flow time of the product model is also minimized under this condition. See Table 2 for the details of the simulation results. The utilization rates for facilities are shown in Table 3. Note that the utilization rate for the auto varnishing facility is measured in terms of average number of hangers with cores since the operation is performed using a trolley conveyor.

3.2. *Overwork, setup time reduction, and productivity improvement*

Krajewski *et al.* [4], based on their simulation studies, reported that simultaneously reducing setup times and lot sizes seems to be the most effective way to cut WIP and improve customer service. Six additional experiments have been performed to investigate the effect of overwork, setup time reduction, and productivity improvement (in terms of loss rate) on the system performances. The results are summarized in Table 4. In the experiments we have used the estimated demand data in year 4. If there is no productivity improvement, the buffer sizes increase tremendously (Experiment 8). Consequently, productivity improvement activities are very important to reduce WIP inventories. Setup time reduction is also a key factor to maintain small buffer sizes which confirms the Japanese practices [5].

3.3. *Demand increase*

We also carried out experiments to see the effect of increasing demand in the future. This experiment is important to propose a layout which is a long-term decision. The buffer sizes increase moderately, and productivity improvement activities, setup time reductions, efficient production planning rules must be exercised to make the current buffer spaces feasible.

4. COMPARISONS OF ALTERNATIVE LAYOUTS

Three alternative layouts are proposed by factory engineers. Layouts A and B are proposed before performing the simulation study. Layout C has been proposed after performing the simulation study, so it fully considers the buffer spaces obtained from the study. The detailed layouts drawn using Autocad are shown in Fig. 6. In this section, we compare three layouts. The characteristics of the layouts are summarized below.

Table 4. Effect of overwork, setup time reduction, and productivity improvement (unit: unit)

Average number of flatcars		Exp 7	Exp 8	Exp 9	Exp 10	Exp 11	Exp 12
Auto	Core stock	2.4	11.7	2.4	2.4	2.2	2.2
	After winding	3.4	14.8	2.3	2.3	2.8	2.8
Manual	Core stock	3.1	13.1	3.2	3.2	3.0	3.0
	After winding	7.8	18.5	3.6	3.6	4.2	4.2
After forming		4.4	4.7	4.4	4.4	4.6	4.6
Subtotal		22.5	64.8	17.1	17.1	18.1	18.1
Buffer for the assembly line		24.7	13.9	27.0	17.2	28.9	18.9
Total		47.2	78.7	44.1	34.3	47.0	37.0

- Description of experimental conditions.

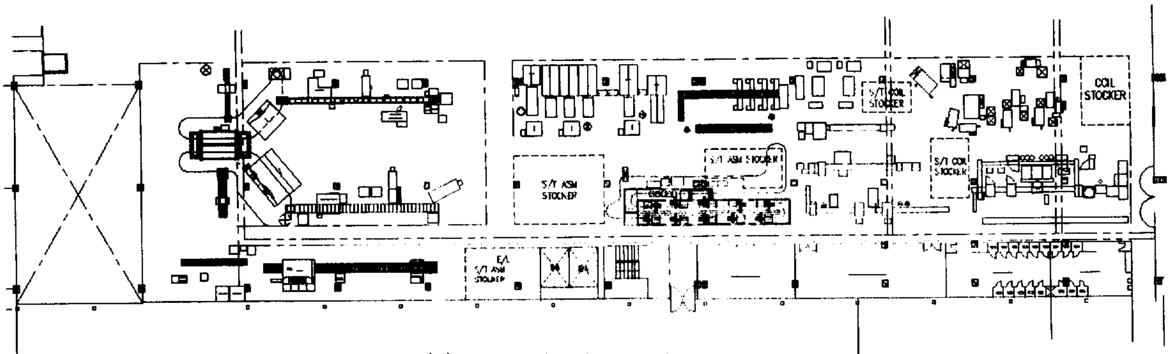
Exp 7. Basic conditions and estimated demand data in year 4.
Exp 8. Use productivity data of year 0.
Exp 9. Overwork for forming operation (580 min→640 min).
Exp 10. Overwork for forming operation (580 min→640 min work) and 1 day reduction of due date.
Exp 11. 50% setup time reduction.
Exp 12. 50% setup time reduction and 1 day reduction of due date.

Table 5. Effect of demand increase

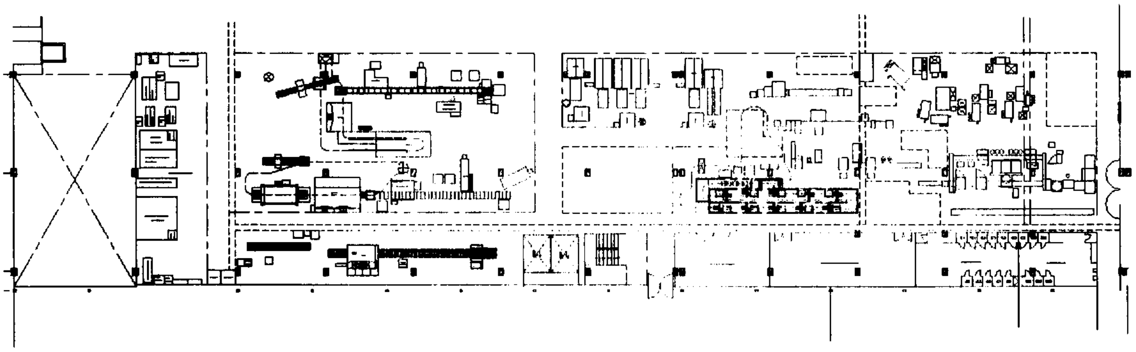
Average number of flatcars (unit: unit)		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Auto	Core stock	2.4	2.5	2.6	2.4	2.5	2.5
	After winding	3.6	3.3	3.4	3.4	3.0	3.0
Manual	Core stock	2.7	3.6	3.6	3.1	2.9	2.8
	After winding	5.0	5.5	6.5	7.8	6.1	8.1
After forming		3.6	4.0	4.4	4.4	5.0	5.8
Subtotal		19.2	19.6	21.5	22.5	22.5	26.0
Buffer for the assembly line		21.8	21.8	23.4	24.7	28.0	24.7
Total		41.0	41.4	44.9	47.2	50.5	50.7
Flow time (unit: min)	After forming section I	3369	2809	2838	2647	2467	2410
	After forming section II	3576	3236	3323	3398	2987	3181
	Before assembly	6929	6274	6316	6257	6229	6497

(1) Alternative layout (A)

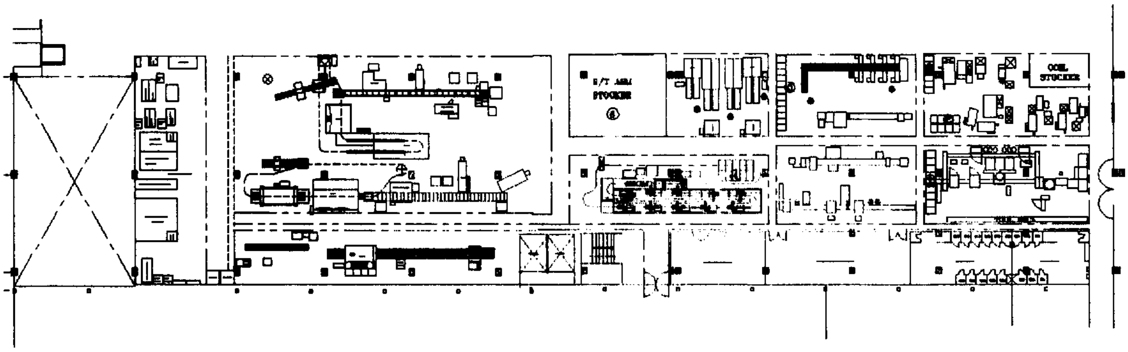
1. A layout that admits the shape of the existing facility.
2. Material flow is smooth but the spaces for passages are not secured.



(a) alternative layout A



(b) alternative layout B



(c) alternative layout C

Fig. 6. Three alternative layouts.

Table 6. Evaluation sheet of alternative layouts

No.	Factor	Weight	Alternatives A	B	C
1	Space utilization	4	2	3	4
2	Efficiency of flow	2	3	2	4
3	Moving expenses	2	2	3	3
4	Facility utilization	2	3	3	5
5	Flexibility of production	2	2	3	4
6	Inventory and lead time reduction	1	4	4	4
7	Ease of control	1	3	2	5
8	Ease of production control	1	4	3	4
9	Labor utilization	1	4	4	4
10	Productivity	1	4	3	4
11	Facility maintenance	0.6	3	4	4
12	Safety	0.6	3	3	4
13	Coordination of supporting facilities	0.6	3	3	3
14	Adaptability and diversity	0.6	3	3	4
15	Ease of expansion	0.6	3	4	4
	Total	20	56	60.2	80.4

Ex) grade: excellent (5); good (4); medium (3); poor (2); bad (1).

3. Rebuilding and moving the assembly line is required. Especially, an inspection facility and a painting facility must be moved.
4. It is difficult to control production because buffers for the assembly line are separated.

(2) Alternative layout (B)

1. A layout that admits the shape of the existing facility.
2. The spaces for passages are not secured and material flow is complex. Especially, the material flow of the auto varnishing trolley is complex.

(3) Alternative layout (C)

1. A layout based on the simulation result.
2. The spaces for passages are secured and material flow is smooth.
3. Need to rebuild preheaters and driers for batch varnishing operations.

Three layouts are evaluated by a committee composed of a manager, a foreman, an industrial engineer, and several other engineers. A factor-weighting method has been used, and fifteen factors including space utilization, moving expenses, lead time reduction have been considered [6]. We assigned a weight to each factor to reflect its relative importance in the firm's objectives. The scale for each factor is set 1 to 5. After the committee scored each layout for each factor, the total score for each layout has been computed by multiplying the score by the weights for each factor (Table 6). Layout C got the highest score, and was recommended to the management.

5. CONCLUSIONS

In this article, we presented a simulation model for an existing motor production factory. Some observations made from this simulation study are as follows:

Firstly, the capacity problem which might arise in several years time as the result of increasing demand can be overcome provided that the productivity goal can be achieved. Consequently, no further investment to new facilities would be required. However, the forming operation can be a bottleneck operation. In that case, the bottleneck can be resolved by extending the operation time from 580 min to 640 min.

Secondly, since there are significant differences between flow times to the varnishing operation and to the assembly line, a study to establish efficient dispatching rules considering flow time is needed.

Thirdly, a layout which considers the statistics obtained from the simulation study has been rated first in terms of space utilization, production flexibility, efficiency of material flow, etc.

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