A Simulation Study on the Effect of Reconfiguration Strategy in an Automotive Body Shop Considering the Change of Product-mix

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Abstract: In this paper, we consider the manufacturing system of an automotive body shop in which two types of car are produced and one car is substituted by the other car gradually. There are two different underbody lines because the underbody structures of the two types of car are absolutely different. We also consider the reconfiguration strategies for changing the layouts as the changes of the product-mix. The effects of reconfiguration strategies and buffer allocations are investigated by simulation experiments.

1 INTRODUCTION

The body shop of an automotive factory is the typical manufacturing system which consists of 15~20 sub-lines and many assembly operations (Moon et al., 2006). Sub-lines in an automotive body shop are divided into some groups, such as under body lines, side body lines, main body lines, opening parts lines and body in white lines.

There have been only a few papers dealing the manufacturing systems of automotive body shops. Muhl et al. (2003) explained the overall processes of automotive factory and introduced some issues. Spieckermann et al. (2000), Kahan et al. (2009) and Tahar and Adham (2010) presented papers related to the body shop design using simulation. Gupta et al. (2012) discussed a methodology for automating the welding gun selection processes and optimized to reduce gun variants in an automotive body shop. Moon et al. (2006) presented a paper which considered the case study of a design procedures using 3D simulation for an automotive body shop. Feno et al. (2014) proposed a concept design processes in the early phase of automotive body shop design, and explained the integration of digital manufacturing technologies and simulations.

Kim et al. (2015) compared two different layout, 'layered build method' and 'modular build method' with respect to the welding methods in the side body sub-lines. Moon et al. (2017) also compared two types of part transfer policies which can be applied to the sub-lines in which no buffers are allowed. The first policy is the 'synchronous transfer' and the second policy is the 'asynchronous transfer'. Moon et al. (2016) suggested that the gap of throughput between the two layout structures could be reduced by decoupling a main body subline and by optimizing buffer allocations. However, these papers assumed that there is only on type of car, and did not consider the under body sub-lines.

The mixed-models production, which means that two or more types of cars are produced in the same line (or shop), is popular in automotive industries. In general, all the cars of mixed-models have similar body structures and similar welding operations. Unfortunately, it is very difficult to develop

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mathematical models considering mixed-models production. Moon et al. (2018) investigated the effect of mixed-model production in a body shop using simulation, but they did not consider under body lines.

As the increasing demands of eco-friendly car such as hybrid cars or electric cars, most of automotive companies are confronted to change the layout concept of body shop. In general, they produce both hybrid car and internal combustion engine type car (we call it as the engine car) for the same car model in the same line, because both of cars can share same body structures. In the case of hybrid car with front-wheel drive, engine, motor and transmission are installed in the front of car body, and battery pack and fuel tank are usually installed in the rear area of car body.

However, in an electric car, a flat battery pack is installed on whole underbody because of weight balance. Thus, the under body structure of electric car is distinguished from that of engine car by its fully enclosed, smooth underbody. Furthermore, the material of the underbody of electric car can be different from that of engine car, and it results in different adhesive operations. It is the reason that automotive companies tend to separate under body line as the two, one for engine car (or hybrid car) and the other for electric car. This is one of the motives of our study.

Another situation considered in this paper is reconfiguration. At the beginning, the production quantity of electric car is small, but the demand of electric car increases and it will substitute the engine car gradually. Thus, the capacity of the under body line of electric car should be expanded, and that of engine car should be downsized. It means that the layouts of the two types of cars should be changed, and the reconfiguration strategies are required.

In this paper, we will briefly investigate the effect of reconfiguration strategies by simulation study, when the product-mix is changed in an automotive body shop. This paper is organized as follow. In section 2, the system configuration is described, and the simulation results are explained in section 3. Finally conclusion and discussions are addressed in section 4.

2 SYSYEM CONFIGURATIONS

2.1 Basic Configurations

To evaluate the reconfiguration strategies for under body lines in automotive body shop, we define the abstract model of automotive body shop as shown in Figure 1, and the following assumptions are applied to the system.

- Both engine car and electric car are produced for the same car model. The total target production volume is fixed, but individual production volume is changed following to the product-mix.
- All sub-lines except for underbody lines can be shared. However, there are two types of under body lines, one for engine car and the other for electric car. The layout of underbody lines for engine car is similar with the traditional layout. However, the structure of underbody lines for electric car is designed with the concept of cell system because the production volume is not high. When the production volume of electric car increases we can install additional cell lines in parallel.
- The welding method of side body is the modular build method.
- The transfer policies in all sub-lines are asynchronous transfer.
- There are buffers between two successive sub-lines (total number of buffer location is 14), but no buffers are allowed in a sub-line.
- The process times (PT) of all stations in upper body (side body and main body) sub-lines and opening parts sub-lines are known and constant as one time unit (minute) because a body shop is a highly automated manufacturing system.
- The process times of underbody lines(or cells) can be varied by the change of the product-mix of two types of cars. The total workload is fixed, and thus process time of a workstation is determined by the number of work stations. We assume that perfect line balancing is possible.
- There is only one mode of time-dependent failure for all workstations, and the distributions of time to failure (uptime) and repair time (downtime) are known and same. Exponential distributions are assumed, and MTTF and MTTR are set to 240 and 10 time units, respectively. Thus, the isolated efficiency of a workstation is 0.96.
- There is no starvation in the first stations and there is no blocking in the final station. The first stations mean the stations which do not have predecessors, and the final station is the station that does not have successors.

Table 1 shows the basic layout data of the two underbody lines. The total workload of the underbody line of engine car (TW_1) is 24 and that of electric car (TW_2) is 21. This assumption is reasonable because the underbody structure of electric car is simpler than that of engine car. The total number of stations of engine car (NS_1) is 24 and that of electric car (NS_2) is

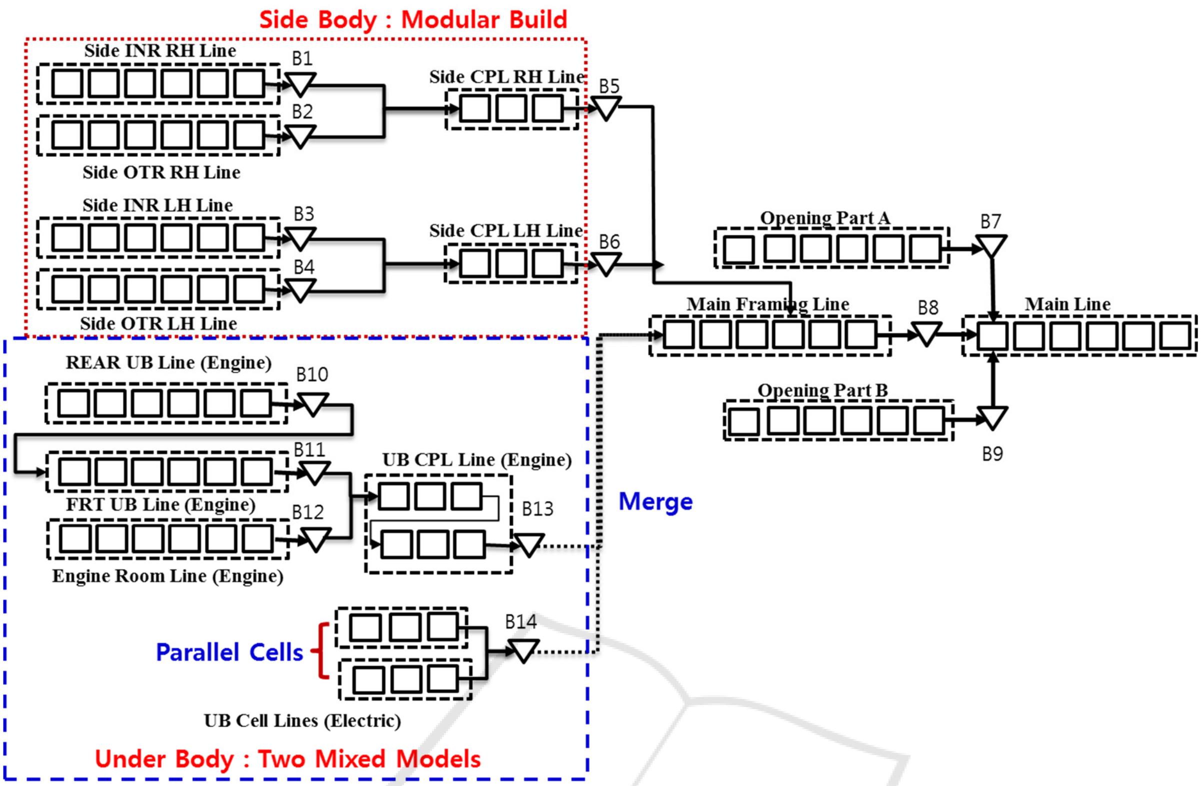

Figure 1: Abstract model of automotive body shop.

three. Thus the process times of a station (PT_1 and PT_2) are calculated by the equation (1), and the values are one and seven, respectively.

Table 1: Basic data of two underbody lines.

	Engine car (Type 1)	Electric car (Type 2)
TW_i	24	21
NS_i	24	3
PT_i	1	7

$$PT_i = \frac{TW_i}{NS_i} \quad (1)$$

2.2 Reconfiguration Strategies

The following three reconfiguration strategies are considered.

- Strategy 1

Although the production volume of engine car decreases as the increase of product-mix (add new cell lines for electric car), we did not change NS_1 and PT_1 as shown in Table 2.

Table 2: Data for strategy 1.

Electric car (Type 2)		Engine car (Type 1)	
Product-mix	Number of Cell Lines	NS_i	PT_i
0%	0	24	1.0
10%	1	24	1.0
20%	2	24	1.0
30%	3	24	1.0
40%	4	24	1.0
50%	5	24	1.0

- Strategy 2

If the production volume of electric car increases, we delete some stations in the under body lines of engine car following to the Table 3. In this case, the positions of stations to be deleted should be determined by the scenario in Figure 2. When product-mix becomes 10%, we can deleted two workstations marked with ① in Figure 2. Then, the process time PT_1 is re-calculated by the relationship in equation (1). In strategy 2, we can reduce the additional spaces required for adding new cell lines for electric car.

Table 3: Data for strategy 2 and 3.

Electric car (Type 2)		Engine car (Type 1)	
Product-mix	Number of Cell Lines	NS_i	PT_i
0%	0	24	1.0000
10%	1	22	1.0909
20%	2	20	1.2000
30%	3	17	1.4118
40%	4	15	1.6000
50%	5	12	2.0000

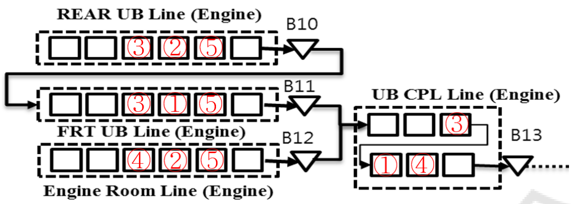

Figure 2: Positions of workstations to be deleted.

- Strategy 3

In strategy 3, the stations to be deleted are substituted to buffers. Thus, the data and buffer positions for strategy 3 are the same as in Table 3 and Figure 2, respectively. In strategies 1 and 3, we need additional spaces for electric car.

3 SIMULATION RESULTS

The simulation models are developed with ARENA® (see Rossetti, 2016). Simulation run length is set to 330,000 including 30,000 of warmup time, and the number of replication is ten. The main performance measure is production rate, and it is calculated by the equation (2).

$$PR = \frac{Total\ production\ quantities}{300{,}000} \quad (2)$$

For the experiments the buffer capacities of B_1~B_{13} are assumed as same, and they are set to 1, 3, 5, 7 and 11. On the other hand, the buffer capacity of B_{14} is set to 1, 3 and 5, respectively. The product-mix has been changed from 10% to 50%. Some of the simulation results are summarized in Table 4. The ranges of 95% confidence intervals are ($\pm 0.001 \sim \pm 0.002$).

The simulation results indicate that the production rate increases as the increase of the product-mix of electric car. It means that the layout structure of parallel cell lines gives positive effects on the production rate.

The second observation is that the strategy 3 is always better than those of the other strategies, consistently. It is due to the effect of new allocation of buffer in some underbody sub-lines of engine car.

Table 4: Simulation Results.

Buffer Capacity		Strategy 1				Strategy 2				Strategy 3			
B1 ~ B13	B14	Product-mix				Product-mix				Product-mix			
		10%	20%	30%	50%	10%	20%	30%	50%	10%	20%	30%	50%
1	1	0.2457	0.2523	0.2583	0.2669	0.2446	0.2505	0.2539	0.2619	0.2493	0.2555	0.2615	0.2718
	3	0.2462	0.2520	0.2586	0.2678	0.2456	0.2510	0.2544	0.2622	0.2510	0.2563	0.2625	0.2700
	5	0.2475	0.2529	0.2586	0.2669	0.2461	0.2516	0.2542	0.2632	0.2516	0.2558	0.2630	0.2703
3	1	0.3129	0.3217	0.3283	0.3393	0.3110	0.3209	0.3268	0.3369	0.3172	0.3254	0.3341	0.3430
	3	0.3160	0.3228	0.3289	0.3406	0.3143	0.3214	0.3278	0.3387	0.3204	0.3260	0.3337	0.3438
	5	0.3145	0.3229	0.3290	0.3388	0.3137	0.3219	0.3274	0.3378	0.3196	0.3250	0.3338	0.3443
5	1	0.3665	0.3769	0.3845	0.3953	0.3671	0.3758	0.3832	0.3934	0.3702	0.3809	0.3888	0.3991
	3	0.3699	0.3779	0.3873	0.3966	0.3708	0.3777	0.3847	0.3966	0.3739	0.3812	0.3906	0.3982
	5	0.3710	0.3801	0.3872	0.3958	0.3714	0.3776	0.3839	0.3964	0.3735	0.3829	0.3902	0.3987
7	1	0.4097	0.4214	0.4309	0.4396	0.4088	0.4201	0.4277	0.4384	0.4140	0.4246	0.4334	0.4430
	3	0.4145	0.4245	0.4322	0.4407	0.4148	0.4217	0.4298	0.4405	0.4180	0.4265	0.4346	0.4438
	5	0.4150	0.4248	0.4303	0.4414	0.4147	0.4235	0.4305	0.4408	0.4193	0.4265	0.4340	0.4428

The role of new buffer is to decouple sub-lines and it reduces the length of flow lines with no buffer. However, the gaps decrease as the increase of buffer capacities. In most cases, strategy 1 is slightly better than strategy 2. Note that strategies 1 and 3 require more spaces for installing new cell lines of electric car.

Figure 3 shows the behaviour of production rates when the buffer capacities of B_1~B_{13} are set to 5, and B_{14} is set to 3. Figure 4 shows the behaviour of production rates when the buffer capacities of B_1~B_{13} are set to 7, and B_{14} is set to 5. We can observe that the gap between strategy 1 and strategy 2 is reduced as the increase of buffer capacities.

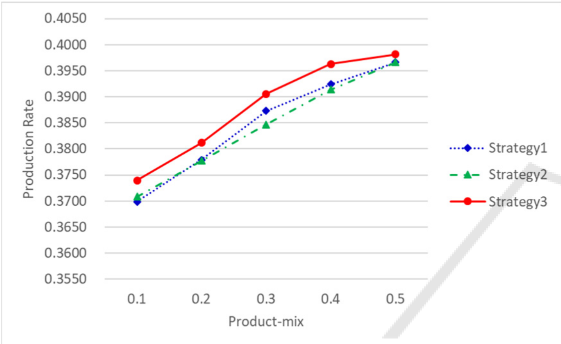

Figure 3: Behaviour of production rates (B_1~B_{13}=5, B_{14}=3).

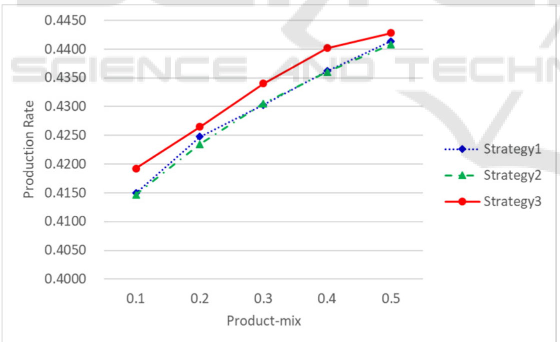

Figure 4: Behaviour of production rates (B_1~B_{13}=7, B_{14}=5).

4 CONCLUSIONS

As the increasing demands of eco-friendly car such as hybrid cars or electric cars, most of automotive companies are confronted to change the layout concept of body shop. In this paper, we consider the manufacturing system design problem of an automotive body shop in which two types of car are produced and engine car is substituted by electric car gradually. Thus, two different underbody lines are installed because the underbody structures of the two types of car are absolutely different. We also consider the reconfiguration strategies for changing the layouts as the changes of the product-mix.

In this paper, only the production rate is considered as the performance measure. However, additional investment costs and space costs are required for the reconfiguration of manufacturing system. Thus, multi-objectives problem can be considered. Another extension is to develop new reconfiguration strategies and optimize the buffer location when there are surplus workstations caused by the changes of product-mix. To solve the extended problems, meta-modelling approach can be used for optimize the new problem.

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