A BUFFER ALLOCATION PROBLEM IN AUTOMOTIVE BODY SHOP

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ABSTRACT
Body shop in an automotive factory consists of many sub-lines which are highly automated transfer line, and the sub-lines are merged in many assembly operations. To design a body shop, the layout concepts based on welding technologies, the part transfer policies in sub-lines, and the buffer allocation problems should be considered and optimized. In this study, we will suggest guide lines for designing a body shop using simulation experiments. The major concerns are which sub-line should be decoupled and how to distribute the limited total buffers in the layered build layout to increase the production rate near to that of modular build layout.

Keywords: workstation design, work measurement, ergonomics, decision support system

1. INTRODUCTION
The body shop of an automotive factory is the typical manufacturing system which consists of many assembly operations and the concept of layout is a flow lines (or transfer lines). Moon et al. (2006) explain that the body shop is divided into 15~20 sub-assembly lines in general. In each sub-line many welding operations are processed and the welding operations are assigned to many serial stations considering the line balancing. Thus, more than one welding operations are assigned to a station.

Generally, no buffer is allowed in a sub-line because available space is limited and they want to reduce WIP (Work in Process). On the other hand, finite buffers are allowed between two successive sub-lines for reducing the risk caused by and unexpected blocking and starving. The electric monorail system (EMS) is usually installed in the body shop for conveying and storing parts.

Moon et al. (2006) describe the design processes for body shops of automotive factories. Some decision makings are encountered at the initial phase of designing the body shop. The first decision is which welding method is adopted for constructing car-body (see Wang, 2014; Kim et al., 2015). There are two types of welding methods used in body shops and they are "layered build method" and "modular build method". Figure 1 is the concept of layered build method and Figure 2 is the concept of modular build method, respectively. Some say that the strength of welded body is higher when it is assembled by the layered build method, and it also has the merit of the accessibilities of robot guns. However, the layered build method has the weakness of the over-load in the main body sub-line, and thus the longest line length is increased (Kim et al., 2015). Figure 3 and Figure 4 are the abstract layout models which adapt the layered build method and the modular build method, respectively (Wang, 2014; Kim et al., 2015; Moon et al. 2016). In their articles, the throughput of the modular build layout is higher than that of the layered build layout when transfer policy is synchronous.

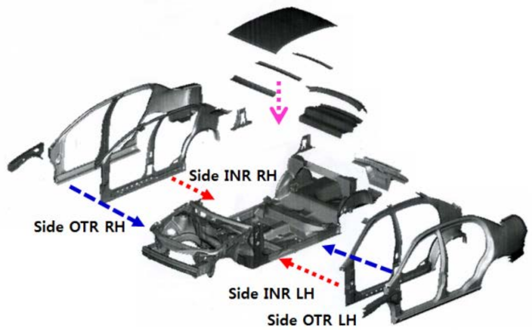

Figure 1: Concept of Layered Build Method (Kim et al. 2015; Moon et al. 2016)

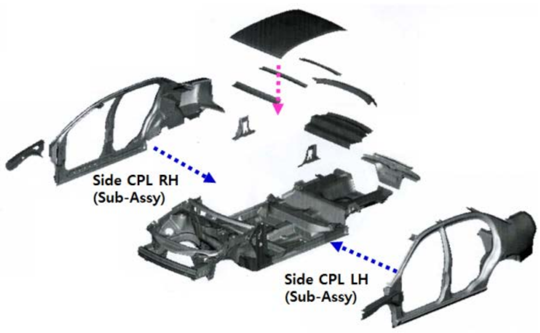

Figure 2: Concept of Modular Build Method (Kim et al. 2015; Moon et al. 2016)

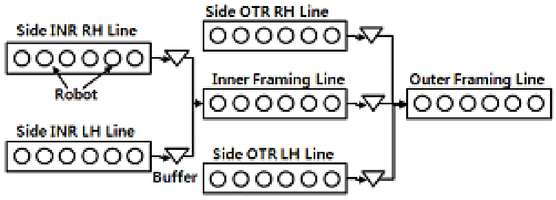

Figure 3: Abstract Layout of Layered Build Method (Wang, 2014; Kim et al., 2015; Moon et al. 2016)

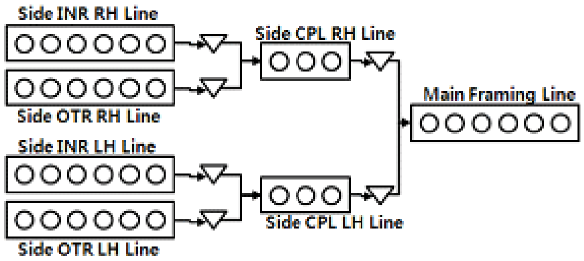

Figure 4: Abstract Layout of Modular Build Method (Wang, 2014; Kim et al., 2015; Moon et al. 2016)

The second decision is for the sub-line design and it is to determine the part transfer policy in a sub-line. Moon et al. (2016) explained that there are two types of part transfer policies which can be applied to the sub-lines with no buffer. The first one is the 'synchronous transfer" and the second is the "asynchronous transfer". In the synchronous policy stations are coupled perfectly by a transfer device and all parts on the stations of a flow line move to the next stations at the same time. In the asynchronous policy the transfer operation of a particular part to the next station is independent from others. There have been many researches considering transfer policies in flow lines such as Dallery and Gershwin (1992), Kalir and Sarin (2009) and Bertterton and Cox III (2012). Moon et al. (2016) compare the transfer policies in two different layouts of the body shop and assessed that the asynchronous transfer is better with respect to the throughput. However, it is known that the investment cost of synchronous transfer is cheaper and easy to control.

The third decision is how many buffer positions are required and how to allocate total buffers to buffer positions. There have been many works dealing the optimal buffer allocation problems in flow lines and assembly lines, but most of them focus on determining buffer size when buffer positions are predetermined (Powell and Pyke, 1996; Papadopoulos et al., 2013; Demir et al., 2013; Nahas et al., 2014). They considered various types of objective functions such as maximizing profit or maximizing throughput. To optimize the problem various optimization algorithms have been used such as genetic algorithm, search algorithm and heuristic algorithms.

In this study we suggest a strategy how to increase the production rate of the layered build layout by splitting a subline and allocating buffer between the split sub-lines.

2. SYSTEM DESCRIPTION

To evaluate the buffer allocating strategy the two systems introduced in Figures 3 and 4 are considered and the following assumptions are applied to these systems:

① The total numbers of welding operations (number of stations) are the same and they are assumed to be 36.

② Each sub-line has six stations, and there is no buffer between stations in each sub-line. However, in Figure 4, the Side_CPL_LH line and the Side_CPL_RH line are assumed to have only three stations for balancing the total workloads.

③ There are buffers between two sub-lines, and the total number of buffers is assumed to be the same in both models. The number of buffer locations in Figure 3 is five and in Figure 4 there are six. Thus, we assume that the buffer capacity of each buffer is six in Figure 3 and five in Figure 4, respectively, when the total number of buffers is set to 30.

④ The cycle times of all welding operations are known and constant as one time unit (minute) because a body shop is a highly automated manufacturing system.

⑤ There is only one mode of time-dependent failure for all operations and the distributions of uptime and downtime are known and the same. Exponential distributions are assumed.

⑥ There is no starvation in the first stations and there is no blocking in the final stations. The first station denotes the station that does not have predecessors, and the final station is the station that does not have successors.

An automotive manufacturer want to change its body shop layout from the modular build layout to the layered build layout because they believe that the strength of car-body is stronger and the flexibility to the model change is better when the layered build method is applied. However, Kim et al. (2015) show that the production rate of the modular build layout is slightly better than that of the layered build layout, when synchronous transfer policy is applied and the total capacities of buffers are the same. Although they assume that the total workloads of two layout systems are the same, some engineer insist that the total workload of layered build layout is greater than that of modular build layout, about 5~10% in the main welding lines. If additional welding stations are added to the current layered build layout, it is clear that the production rate must decrease.

Then, how can we increase the production rate of layered build layout to be close to that of the modular build layout? To solve the problem, we will test decoupling the Inner Framing Line (or Outer Framing Line) of the layered build layout. Figure 5 shows the example of Decoupling the Inner Framing Line in Figure 3. In Figure 5, Inner Framing Line is evenly divided into two sub-lines and the numbers of stations are three.

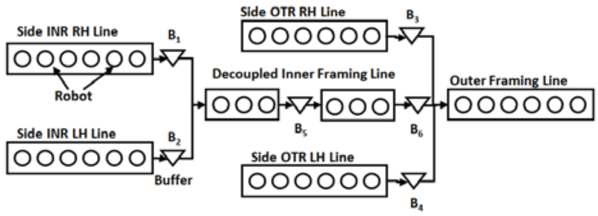

Figure 5: Decoupling Sub-line in Layered Build Layout

3. SIMULATION EXPERIMENT

For investigating the effects of transfer policies on the two layout structures, the following experimental conditions are selected: (the efficiency of isolated station is defined as in equation (1), where MTTF denotes the mean time to failure and MTTR denotes the mean time to repair.

$$e = \frac{MTTF}{MTTF+MTTR} \tag{1}$$

- The failure distribution is the exponential and MTTF and MTTR are 190 and 10, respectively, and thus, the value of e is 0.95
- Total buffer capacity (TB) is set to 30, 60, 90 and 180
- Synchronous and asynchronous transfer policies
- Layered build and modular build layouts

Simulation models are developed with ARENA™. Simulation run time is set to 330,000 time units including a 30,000 unit warmup period and the number of replications is 20. Table 2 shows the results of simulation with respect to the production rates and their 95% confidence intervals.

3.1. Decoupling Sub-line

As explained in section 2, the first scenario (S1) is to decouple the Inner Framing Line of the layered build layout (Figure 3) into two sublines (Figure 5). The second scenario (S2) is decoupling the Outer Framing Line in Figure 3. Then, the number of buffer positions is six and it is the same to that of the modular build layout. The buffer capacity of each buffer location is five. These two scenarios are referred to Latered_S1 and Layered_S2, respectively in Table 1 and Table 2.
Table 1 shows the simulation results when applying the asynchronous transfer policy, and Table 2 is the results of the synchronous transfer policy. In these tables 'Moon' is the results obtained in Moon et al. (2016). Dev1 and Dev2 mean the deviation between two scenarios and calculate as follows.

$$Dev1 = \frac{\left(PR_{Layered\_Moon} - PR_{Modular\_Moon}\right)}{PR_{Modular\_Moon}} \times 100$$

$$Dev2 = \frac{\left(PR_{Layered\_S1} - PR_{Modular\_Moon}\right)}{PR_{Modular\_Moon}} \times 100$$

Table 1: Production Rates (Asynchronous)

Scenario (Layout)		Total Buffer Capacity 30	60	90	180
Modular	Moon	0.4154	0.4943	0.5439	0.6212
Layered	Moon	0.4086	0.4835	0.5308	0.6054
	S1	0.4122	0.4905	0.5396	0.6155
	S2	0.4034	0.4805	0.5300	0.6082
Dev1		-1.63%	-2.18%	-2.41%	-2.55%
Dev2		-0.76%	-0.76%	-0.80%	-0.92%

Table 2: Production Rates (Synchronous)

Scenario (Layout)		Total Buffer Capacity 30	60	90	180
Modular	Moon	0.3756	0.4709	0.5279	0.6137
Layered	Moon	0.3643	0.4562	0.5112	0.5949
	S1	0.3744	0.4680	0.5238	0.6074
	S2	0.3597	0.4540	0.5112	0.5981
Dev1		-3.02%	-3.13%	-3.17%	-3.06%
Dev2		-0.33%	-0.62%	-0.78%	-1.03%

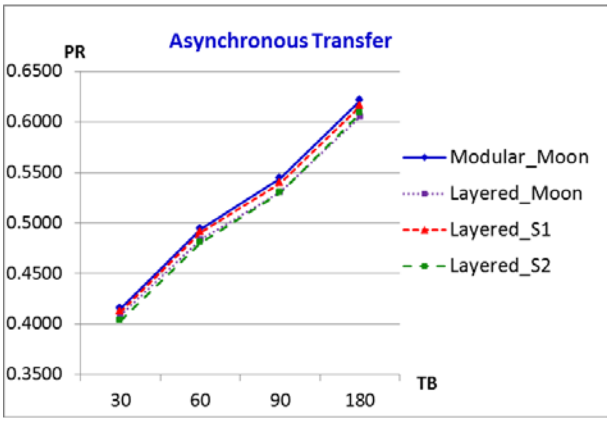

Figure 6: Behavior of Production Rates (Asynchronous)

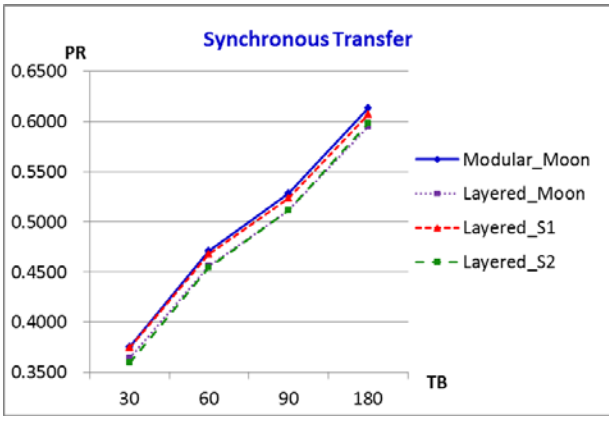

Figure 7: Behavior of Production Rates (Synchronous)

From the simulation experiments we observed that Layered_S1 is effective on the increasing production rate. The production rates become close to those of Modular_Moon. The improvement is higher in the synchronous transfer policy than in the asynchronous transfer policy. However, the decoupling strategy for Outer Framing Line (Layered_S2) shows negative effect. It means that the production rates are rather lower than those of Layered_Moon scenario when the values of TB are 30, 60 and 90. Thus, we don't have to consider Layered_S2 anymore. Figures 7 and 8 show the behaviors of production rates clearly.

3.2. Additional Station

As mentioned in Session 2, there is an opinion that the total workload of layered build layout is greater than that of modular build layout, about 5~10% in the main welding lines. Thus new scenarios are designed for simulation experiments. At first four workstations are assigned to two decoupled sub-lines (scenario S3) and then five workstations are assigned (scenario S4) based on Layered_S1and the same total buffer capacities. The total workloads of S3 and S4 are 38 and 40, respectively. The simulation results are shown in Tables 3 and 4.

Table 3: Effect of Additional Stations (Asynchronous)

Scenario (Layout)		Total Buffer Capacity			
		30	60	90	180
Modular	Moon	0.4154	0.4943	0.5439	0.6212
Layered	S1	0.4122	0.4905	0.5396	0.6155
	S3	0.3970	0.4757	0.5261	0.6063
	S4	0.3849	0.4620	0.5123	0.5942
S1-S3		0.0152	0.0149	0.0135	0.0092
S3-S4		0.0121	0.0137	0.0138	0.0121

Table 4: Effect of Additional Stations (Synchronous)

Scenario (Layout)		Total Buffer Capacity			
		30	60	90	180
Modular	Moon	0.3756	0.4709	0.5279	0.6137
Layered	S1	0.3744	0.4680	0.5238	0.6074
	S3	0.3571	0.4519	0.5095	0.5975
	S4	0.3408	0.4357	0.4941	0.5850
S1-S3		0.0173	0.0160	0.0143	0.0098
S3-S4		0.0163	0.0163	0.0154	0.0125

We anticipate that the assignment of additional stations to the decoupled sub-lines will not critically influence on the production rate because the number of stations is increased to four from three and the maximum number of stations in a sub-line is six. However, simulation results show that the effect of increasing station is not negligible. The decrements of production rates are slightly bigger in the synchronous policy rather than asynchronous policy.

Figures 8 and Figure 9 show the behaviors of production rates for scenarios S1, S2 and S3 when the total buffer capacity increases from 30 to 180 and two different transfer policies are applied.

4. CONCLUSIONS

In this study we considered the possibility that could make the production rate of the modular build layout and that of the layered build layout equivalent by simulation experiments. We tested a decoupling strategy to the main assembly sub-lines in the layered build layout, e.g., Inner Framing Line and Outer Framing Line. The decoupling of the Inner Framing Line and allocating additional buffer location between the decoupled sub-lines was an alternative for improving production rate of the layered build layout. We also investigated the behaviors of production rates when additional station is assigned to the decoupled sub-lines, because there is an opinion that the total workload of the layered build layout is greater than that of the modular build layout.

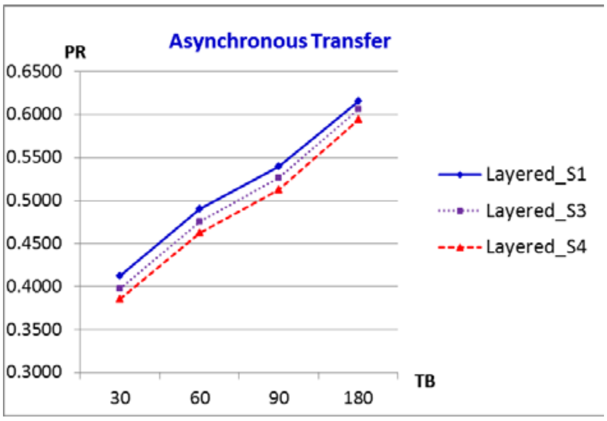

Figure 8: Effect of Additional Stations (Asynchronous)

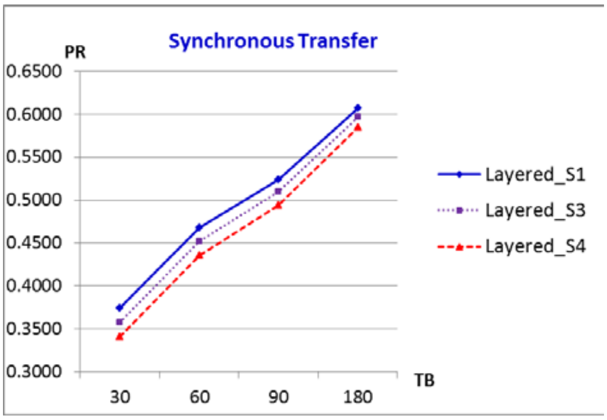

Figure 9: Effect of Additional Stations (Synchronous)

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