A plant simulation approach applied sequencing strategies for buffer prediction: A case study in an automotive assembly line

Anan Butrat*

Department of Industrial Management Engineering, Faculty of Industrial Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage Pathum Thani Province

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Abstract

In this study, a plant simulation approach to buffer prediction for an automotive assembly line was proposed. Currently, the assembly line has exceeded the buffer size. The idea to reduce buffer size is to increase worker size and sequencing strategy. With simulation, two approaches, including throughput analysis and production time analysis, are proposed. The throughput analysis can find the required buffer sizes for maximizing throughput when the total available time is used. The production time analysis can determine the time spent using each buffer space with a fixed throughput size. In terms of results, the sequencing strategy that produces two normal models and one new model provides the first plan to implement. Without increasing worker size, this strategy can finish 48 cars per shift by using 8 buffer spaces. Moreover, increasing one worker is the second plan so that the throughput of this strategy can reach 58 cars per shift. Additionally, this simulation model highlights the modified Blocking After Station (MBAS) that can define not only buffer usage but also the buffer requirement. This research offers a simulation approach to the prediction of buffet usage and the requirement to define an action plan for an unfamiliar task in the automotive assembly line.

Keywords: Assembly line; Manufacturing; Simulation; Buffer size; Sequencing strategies

1. Introduction

A car assembly line is a manufacturing process where various components and sub-assemblies are put together to create a finished automobile. This process involves a series of workstations, each dedicated to a specific task, and the vehicle moves along a conveyor belt or other automated system to progress through the various stages of assembly. The assembly line is designed to accommodate the production of multiple models or variants of cars. This is common in modern automotive

*Corresponding author: anan.but@vru.ac.th

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manufacturing, where flexibility and the ability to produce various models on the same production line are essential for meeting diverse market demands.

In contemporary automotive manufacturing, the efficient integration of new car models into existing production lines is crucial for meeting market demands and maintaining competitiveness. However, a challenge arises when introducing new models with increased processing times when the assembly workers are not sufficiently familiar with the novel model's intricacies. This challenge manifests in the need for larger buffer sizes within the production line to accommodate the extended processing times and mitigate potential disruptions. The problem at hand revolves around the dynamic relationship between buffer size, worker familiarity, and the successful integration of new car models into the production process. When workers are confronted with unfamiliar tasks, the processing times for assembling the new model tend to exceed those of established models. Consequently, this necessitates an adjustment in the buffer sizes to prevent bottlenecks, production delays, and potential disruptions to the overall production flow.

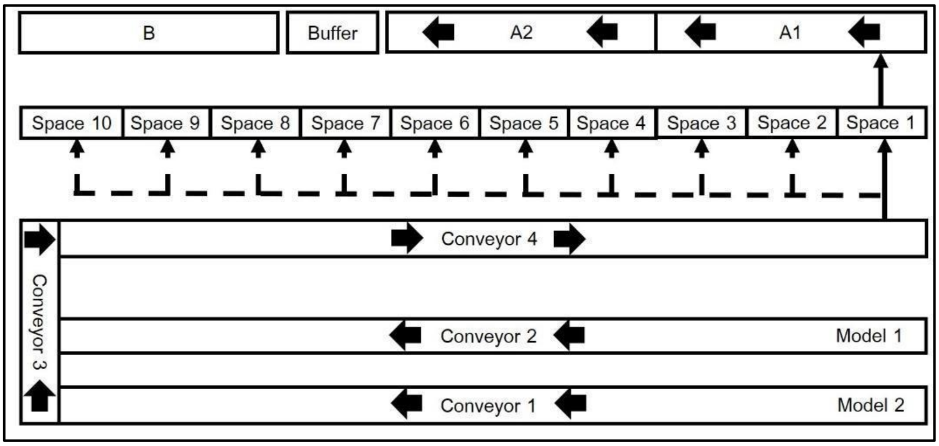

Figure 1. Layout of car assembly line

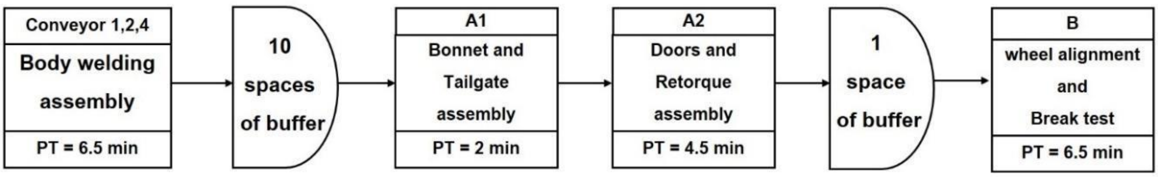

Figure 2. Process flow chart of car assembly line

The focus of this case study is an assembly automotive plant. As shown in Figure 1 and Figure 2, the production line starts at conveyer 1 and conveyer 2. The body parts of both models are assemblied together by welding robots, consuming 6.5 minutes of processing time. Then, both assemblied bodies are transferred from conveyer 3 to conveyer 4 in a 1:1 ratio by alternating. At conveyer 4, all welding spots are checked and inspected for 6.5 minutes per car. After that, all empty bodies are fed to station A1, which is responsible for assembling the bonnet and tailgate in 2 minutes; station A2, which handles the assembly of doors and retorque in 4.5 minutes; and station B, which is responsible for wheel alignment and break testing in 6.5 minutes, respectively. Therefore, this means that the production rate of this assembly line is 6.5 minutes per car.

Within the daily operations, a pair of two standard models, illustrated in Figure 3A, is typically produced at a stable rate of 6.5 minutes per car, as depicted in Figure 2. That means this plant can

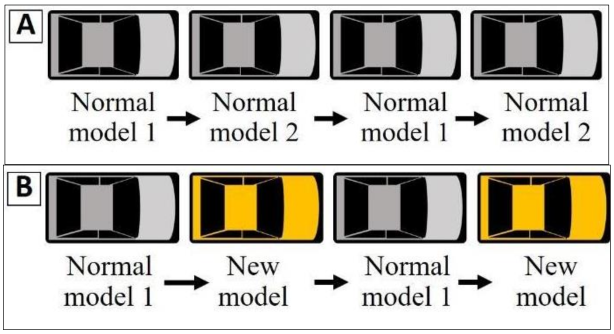

Figure 3. Car assembly line, (A) without new model, (B) with new model

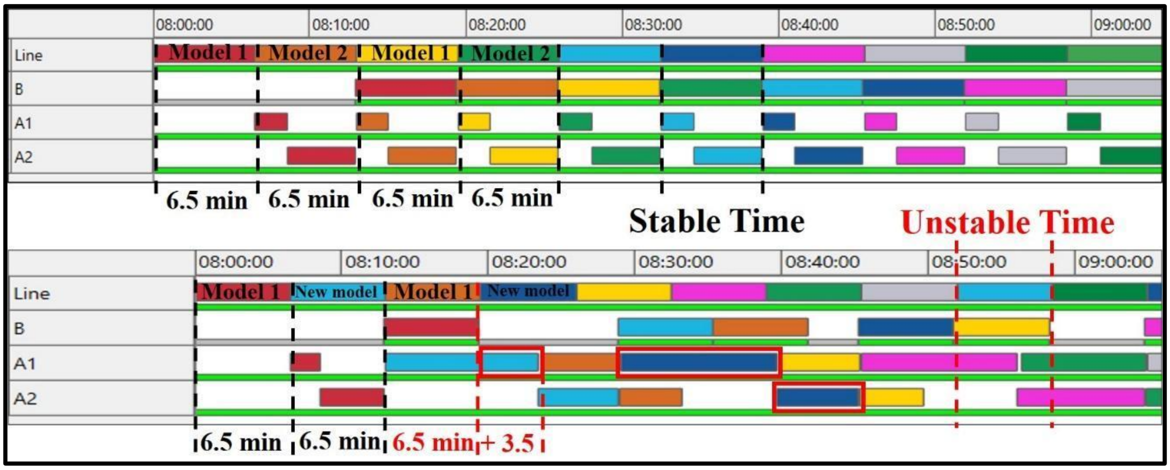

Figure 4. Stable and Unstable production rate

normally produce 68 cars per day. However, the introduction of a new model in a pair, represented by Figure 3B, disrupts the production rate, leading to an unstable workflow, as in Figure 4. The root cause of this disruption lies in the assembly process at stations A1 and A2. Both stations require additional time due to unfamiliarity with the new tasks associated with the new model. With the ratio of one normal and one new model, stations A1 and A2 require more than 6.5 minutes to assemble, as shown in Figure 4, while the first car of the new model requires an additional 3.5 minutes. Consequently, the overall throughput is reduced to 48 cars per day, necessitating the incorporation of buffers between conveyor 4 and station A1.

According to information obtained from the case study company, the buffer size is set at 10 cars. However, a pre-study simulation, as detailed in Table 1, reveals that the actual buffer space is consistently occupied by 10 cars, and an additional 3 spaces are required. Therefore, there is a need for further investigation and optimization in the production process.

Table 1. Comparing the performance of assembly line with and without new model

Cases	Throughput (Units)	Station Utilization (%)				Actual Buffer Usage (Spaces)	Required buffer (Spaces)
		Main	A1	A2	B		
Without new	68	100	100	100	98	0	0
With new	48	100	100	100	68	10	3

Because this study aims to predict buffer utilization and reduce excess buffer sizes through simulation techniques, the literature on two topics is reviewed, including the characteristics of the production line and the analysis method using discrete event simulation. The characteristics of the production line that relate to buffer problems are considered in this study because they are necessary to create the simulation model including production control such as classical flow (FC) (Weiss et al., 2018; Li et al., 2016; Alfieri et al., 2016; Weiss and Stolletz, 2015; Costa et al., 2015; Pedrielli et al., 2015) and CONWIP (CC) (Smith, 2016; Tsadiras et al., 2013; Staley and Kim, 2012; Staley and Kim, 2012; Vergara and Kim, 2009), saturated supply (Li et al., 2016; Alfieri et al., 2016), unsaturated supply (Smith and Daskalaki, 1988; Smith and Cruz, 2005), saturated demand (Li et al., 2016; Alfieri et al., 2016), unsaturated demand (Matta et al., 2014; Pedrielli et al., 2015), Blocking type such as Blocking After Service (BAS) (Weiss et al., 2018; Li et al., 2016) and Blocking Before Service (BBS) (Alfieri et al., 2016; Chiba, 2015), reliable line (Alfieri et al., 2016; Chiba, 2015; Li et al., 2016; Weiss et al., 2018), unreliable line (Weiss and Stolletz, 2015; Kose et al., 2015; Li, 2013), and processing time distribution (Weiss et al., 2018; Li et al., 2016; Kolb and Gottlich, 2015; Costa et al., 2015; Chiba, 2015; Alfieri et al., 2016). Moreover, the previous studies of the analysis methodology using discrete event simulation (DES) were reviewed to find the methodology that can analyze the system of the assembly line such as the throughput analysis (Hema et al., 2022; Vidanelage et al., 2020; Prasad et al., 2019) and production time analysis (Lang et al., 2022; Hannes et al., 2019).

The literature review found that none of the referenced studies in the case of production planning delved into the impact of sequencing strategies on buffer size. The sequencing strategies experiment encompasses the intricate process of establishing the timing and sequence of tasks within a production system. This crucial aspect, often overlooked in existing studies, holds significant potential for influencing and optimizing buffer size dynamics. Moreover, the blocking type in this study is quite specific. Based on BAS with this case study, when 10 spaces between conveyor 4 and A1 are full, conveyor 4 should be blocked and stop the line. However, the real situation is different. Conveyor 4 will continue to feed into the buffer space no matter what happens. Consequentially, this can imply that the blocking type of the case assembly line is not covered by BAS and BBS. Therefore, this study contributes to two research gaps in the problem of excess buffer size. The first one is to illustrate the need for optimized strategies. The second one is to modify BAS to be suitable for finding the required buffer space between the non-stop feeding station and the blocking station.

This study illustrates crafting a model that mirrors the characteristics of an automotive assembly line, especially the unsaturated demand as various sequencing strategies and the blocking type as modification through the addition of a dummy buffer referred to as a variable buffer. The objective of this study is to predict buffer utilization and reduce excess buffer sizes through simulation techniques based on inducators such as throughput and production time. This is to illustrate the need for optimized strategies in the case of the buffer problem, specifically addressing the excess buffer size.

2. Methods

2.1 Modeling the Production System

The model was created using Tecnomatix Plant Simulation based on the layout and process flow chart as illustrated in Figure 5. The charecteristics of the case assembly line are formed as classic flow line control (FC), comprising Source, conveyor 4, ten buffer spaces, station A1, station A2, one buffer space, station B, and Drain, respectively. The source, represented by conveyors 1, 2, and 3, integral to the system, ensures a saturated supply to conveyor 4, alternating between normal and new models in a 1:1 ratio. The source is set to be infinity, the interval time to be 0, and the feeding will occur whenever the conveyer 4 is available. Then, conveyer 4 consumes 6.5 minutes per car before those cars are fed to the dummy buffer. After that, it is in the buffer space that the order starts at buffer 10 and ends at buffer 1 as a first-in, first-out strategy. The rest of the processes are station A1, station A2, one buffer space, and station B, respectively. Additionally, the reliability of the line in the model is established by configuring a zero percentage of failure, thereby enhancing the robustness of the entire assembly process.

The model's specific assumptions are categorized into two distinct types for each approach. The first type used for throughput analysis involves fixing the values in Drain, representing the demand deliberately set to be unsaturated. The termination criterion for Drain is set to conclude the model when it receives 24 cars of the normal model and 24 cars of the new model, for a total of 48 cars. The second type used for production time analysis revolves around fixing the simulation time, concluding when the production time reaches 7.6 hours (7 hours and 36 minutes), aligning with the available time in a single shift.

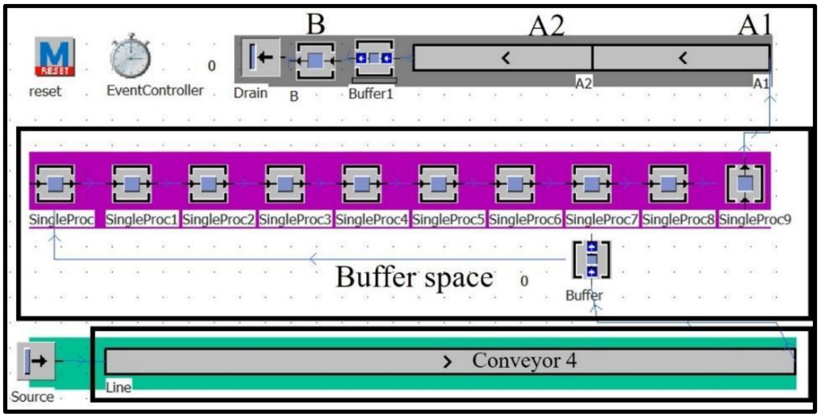

Figure 5. Assembly process model with buffer space

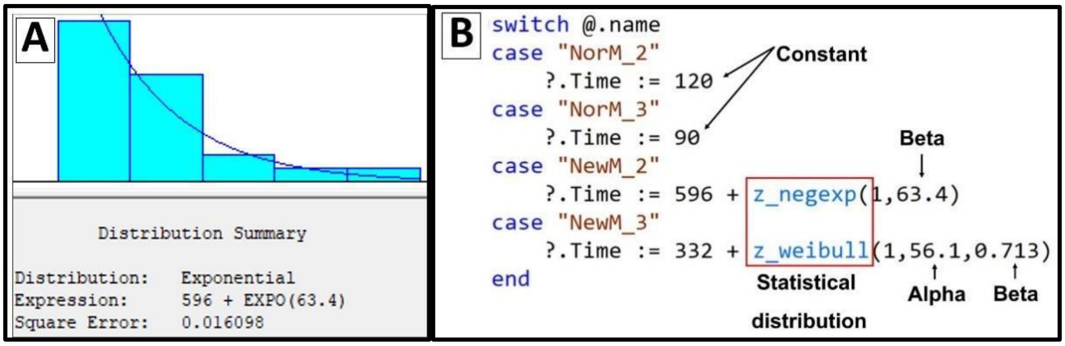

Figure 6. Processing time, (A) Fit distribution data, (B) Setting in simulation

Table 2. Processing time in A1 and A2 with 2 and 3 workers

Model	Processing time of Workstation (seconds)			
	A1		A2	
	2 workers	3 workers	2 workers	3 workers
Normal	120	90	270	225
New	596 + EXPO(63.4)	332 + WEIB(56.1, 0.713)	535 + EXPO(54.5)	289 + EXPO(55.6)

2.2 Time

Because the simulation model applied discrete events, a detailed investigation into the processing time for the new model was conducted to find the fit distribution. The values of the processing time were recorded by using 2 workers at stations A1 and A2 to produce 24 cars. And then, worker size changes to 3 workers, and we try to produce 24 cars again. These recorded times were analyzed and fit to distributions using a program named Input Analyzer based on the least squares error, as shown in Figure 6A. Table 2 provides the data on the processing time for the normal model, representing constant values for both the A1 and A2 workstations and with configurations involving 2 and 3 workers. In addition, the processing time for the new model represents the statistical distribution for both the A1 and A2 workstations, involving 2 and 3 workers, respectively. The statistical distribution includes Exponential (EXPO or z_negexp) that requires beta values and Weibull (WEIB or z_weibull) that requires alpha and beta values. Notably, the processing time for the new model is defined through expressions explicitly set within the model, as shown in Figure 6B. The algorithm named "Switch Case" used to change the processing time in stations A1 and A2 whenever the names of cars (entities) were fixed based on the experiment. For example, "NorM_2" means this entity represents a normal model with two workers.

2.3 Buffer Space

The modified Blocking After Station (MBAS) that is BAS applied to buffer space being between a station that blocks the next part when it is in process and a station that does not stop feeding when the buffer is full introduces a classification of buffers into two distinct types: fixed buffer and variable buffer. The fixed buffer corresponds to the actual buffer size, while the variable buffer is indicative of the required buffer, as Shown in Figure 7. This distinction arises due to the inherent nature of conveyor 4, which operates under the control of conveyors and robots with a constant time constraint, thereby rendering it incapable of coming to a complete halt.

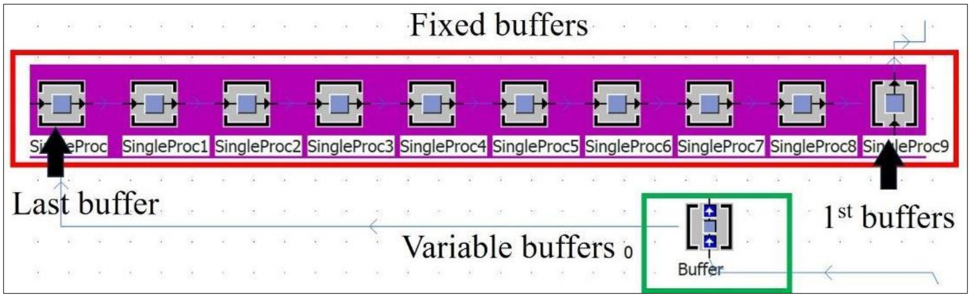

Figure 7. Fixed buffer and Variable buffer

Table 3. All scenario defnition

Strategies	Scenarios											
	C	1	2	3	4	5	6	7	8	9	10	11
Normal	1	2	1	1	2	1	1	2	1	1	2	1
New	1	1	2	1	1	2	1	1	2	1	1	2
A1 Worker	2	2	2	3	3	3	2	2	2	3	3	3
A2 Worker	2	2	2	2	2	2	3	3	3	3	3	3

2.4 Scenario Definition

Designing specific scenarios within the simulation model to represent different combinations of sequencing strategies and worker sizes is shown in Table 3.

This study suggests the incorporation of diverse sequencing strategies into the simulation. The term "various sequencing strategies" refers to the order in which sequences are arranged based on predefined ratios. As shown in Table 3, the sequencing strategies encompass configurations such as 1 normal model to 1 new model, 2 normal models to 1 new model, and 1 normal model to 2 new models.

The simulation incorporates different worker quantities using the traditional method, a common approach employed to address bottleneck challenges. As depicted in Table 3, the number of workers is systematically adjusted, ranging between 2 and 3.

2.5 Analysis approaches

The approaches to this study include production time analysis and throughput analysis. Both approaches are adept at predicting the usage and requirement numbers of the buffer. Production time analysis establishes a discernible relationship between buffer size and production time. The assumption in this approach is to fix the number of throughputs equal to 48 cars and compare the buffer size and production time. The expected values for this approach include the actual buffer size usage, which should be less than or equal to 10 spaces, the required buffer, which should be 0, and the production time, which should be less than 7.6 hours. On the other hand, throughput analysis aims to elucidate the correlation between buffer size and throughput. These approaches collectively contribute to a comprehensive understanding of the dynamics within the assembly model. The assumption in this approach is to fix the production time equal to 7.6 hours and compare the buffer size and throughput instead. The expected values in this approach are the same as in the production time analysis, except for the production time minimization that is changed to find the throughput of over 48 cars instead. Moreover, the action plans are the summarization of all scenarios that show the relationship between the sequencing strategy, worker sizes, and expected values and are analyzed by comparison. The best scenario will be the one that can produce 48 cars with a production time of less than 7.6 hours and none of the excess space requirement and provides the highest throughput under 7.6 hours by using none of the excess space requirement. In addition, the best scenario also needs to provide the lowest labor cost per car from stations A1 and A2.

3. Results and Discussion

3.1 Production time analysis

Upon rectifying the throughput values and exploring various sequencing strategies and worker sizes, the analysis reveals a discernible relationship between buffer usage, space requirements, and production time, as illustrated in Figure 8. Notably, scenarios exhibiting lower space usage and reduced space requirements also boast shorter production times.

The investigation extends to the examination of the impacts of sequencing strategies and worker sizes. In scenario 1, where the ratio of two normal models per one new model is adopted, superior buffer usage is observed compared to scenario 2, which employs a ratio of one normal model per two new models. This can be analyzed by using the graph in Figure 8, which shows the lines including average buffer usage in percentage (green line) and production time (orange line). The production time and average buffer usage of scenario 1 are better than those of scenario 2 when comparing those scenarios with the current situation. Scenario 1 can reduce 0.42 hours and 28% of usage compared to scenario 2, which can reduce 0.02 hours of production time only but increase 28%

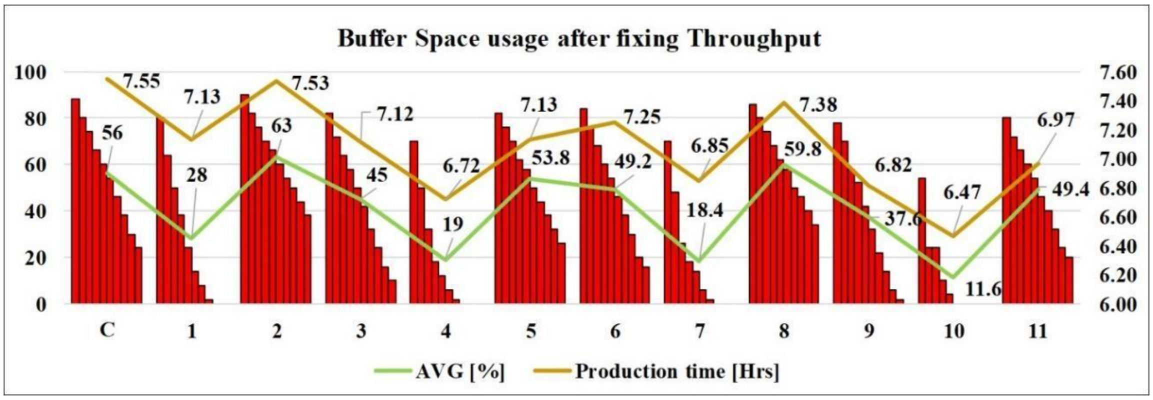

Figure 8. Relationship of buffer space usage and production time

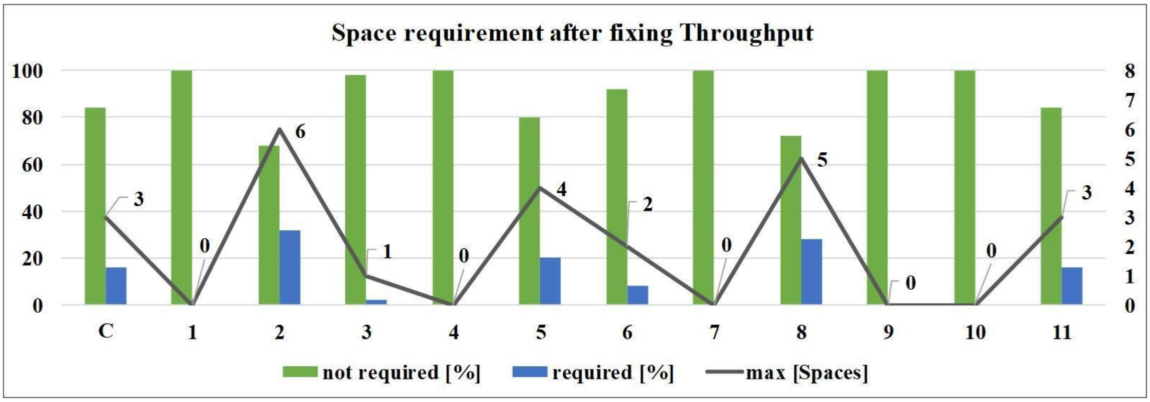

Figure 9. Relationship of space requirement and production time

of usage. Furthermore, an evaluation of various worker size increments, as exemplified in Scenario 3, 6, and 9, indicates a reduction in space usage compared to the current setup. However, it is noteworthy that these alternatives do not surpass the efficiency achieved in scenario 1. Scenario 3 and scenario 9 can reduce the production time more than scenario 1, which only provides 0.43 hours and 11% of usage and 0.73 hours and 18.4% of usage. In addition, scenario 6 does not provide the same result as scenario 1 at all (0.3 hours and % of usage).

The graphical representation (Figure 9) further reinforces the significance of the sequencing strategy. Specifically, setting the ratio to two normal models and one new model, as evidenced in scenarios 1, 4, 7, and 10, results in zero space requirements. This underscores the effectiveness of the sequencing strategy in comparison to merely increasing worker sizes, as demonstrated by the superior outcomes in scenario 1.

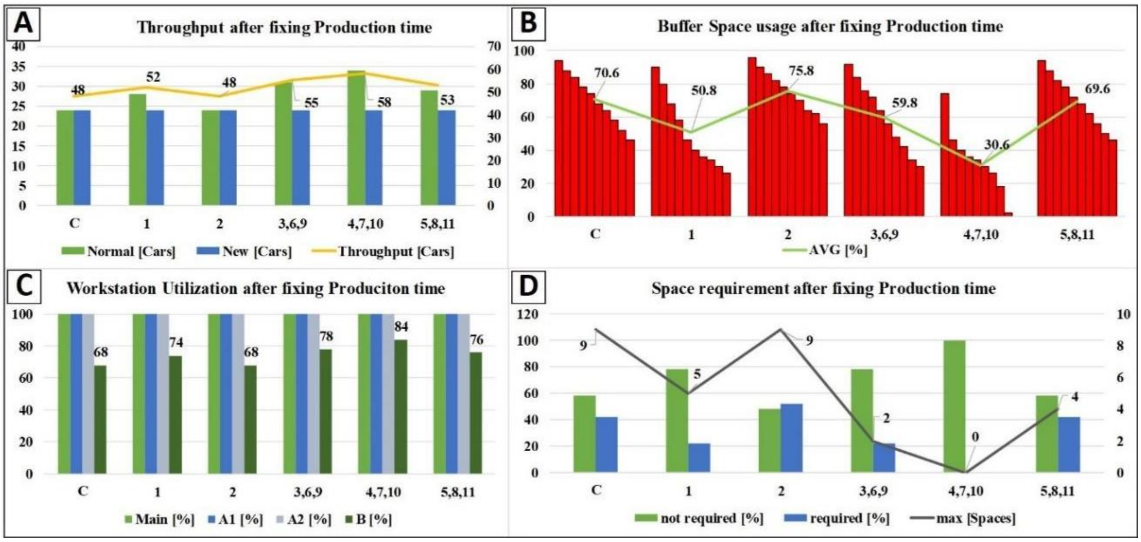

Figure 10. Analysis of fixing production time (A) Throughput, (B) Buffer space usage, (C) Workstation utilization, (D) Space requirement

3.2 Throughput analysis

Upon stabilizing the production time and scrutinizing the variations in throughput, it is evident that adopting a ratio of two normal models to one new model can result in an increase of 4 cars per shift, as depicted in Figure 10A. Additionally, combining this ratio with an increase in worker sizes, as observed in Scenarios 4, 7, and 10, can further elevate throughput to 10 cars per shift.

Furthermore, the analysis reveals that altering worker sizes solely in A1, A2, or both does not yield significant differences in throughput values. To underscore this point, Scenarios 4, 7, and 10 emerge as particularly noteworthy, showcasing the lowest buffer space usage (Figure 10B), optimal workstation utilization (Figure 10C), and a remarkable absence of space requirements. These findings provide valuable insights into the nuanced dynamics of the assembly process.

3.3 Action plans

The action plans and their execution are meticulously analyzed for each scenario. As shown in Table 4, the results of each scenario, including the buffer usage, the buffer requirement, the number of throughputs, the production time, and the labor cost, are illustrated. The possible scenarios, including scenarios 1, 4, 7, 9, and 10, are those in which the numbers of buffer requirements in both cases are 0 and the production time is not greater than 7.6 hours when fixing throughput to 48 cars. This fixes the problem of the case study that needs to produce 2 models, 24 cars each, with 10 buffer spaces as well. Moreover, in the case of the improvement, the possible scenarios are considered by using throughput analysis, and the production time is fixed at 7.6 hours. The scenarios that can provide the highest throughput are scenarios 4, 7, and 10, which can provide 58 cars. Furthermore, when the values of the labor cost are considered, the best scenario should have the lowest cost, which is scenario 4, which requires 2,250 baht. Therefore, the best action plan comes from scenario 4, which applies the sequencing strategy of 2 normal models and 1 new model in the sequence ratio and increases the worker size of station A1 from 2 to 3 workers.

TABLE 4. Summary of all scenarios

Sce.	Sequencing Strategy		Worker sizes		Fixed Throughput to 48 cars			Fixed Production time to 7.6 hours			Labour Cost (Baht)
					Buffer		Production time (Hrs)	Buffer		Throughput (Cars)	
	Norm	New	A1	A2	Actual Usage (Spaces)	Required (Spaces)		Actual Usage (Spaces)	Required (Spaces)		
C	1	1	2	2	10	3	7.55	10	9	48	1,800
1*	2	1	2	2	8	0	7.13	10	5	52	1,800
2	1	2	2	2	10	6	7.53	10	9	48	1,800
3	1	1	3	2	10	1	7.12	10	2	55	2,250
4*	2	1	3	2	7	0	6.72	9	0	58	2,250
5	1	2	3	2	10	4	7.13	10	4	53	2,250
6	1	1	2	3	10	2	7.25	10	2	55	2,250
7*	2	1	2	3	7	0	6.85	9	0	58	2,250
8	1	2	2	3	10	5	7.38	10	4	53	2,250
9*	1	1	3	3	10	0	6.82	10	2	55	2,700
10*	2	1	3	3	5	0	6.47	9	0	58	2,700
11	1	2	3	3	10	3	6.97	10	4	53	2,700

*Possible scenarios

3.4 Discussion

The modified Blocking After Station (MBAS) applies the same concept of BAS: that the completed workpiece cannot move forward because there is no space available in the downstream buffer to define the buffer size, as mentioned in Weiss et al., 2018 and Li et al., 2016. However, the difference in this study is to apply the variable buffer that is used to reconfigure the required buffers when the completed workpiece cannot move forward.

The concept of the unsaturated demand case in this study did not define it as exponential or lognormal capacity, as mentioned by Matta et al., 2014 and Pedrielli et al., 2015. This study concept is to fix the amount of demand as the simulation assumption to predict the production time when strategies are varied.

The unreliable line in this study refers to sequencing strategies that define the ratio of two types of products in a production line. This method provides inconsistent performance as mentioned in Weiss and Stolletz, 2015; Kose et al., 2015 and Li, 2013, such as throughput and resource utilization.

The processing times to assemble the new models also provide the distribution, as mentioned in Weiss et al., 2018; Li et al., 2016; Kolb and Gottlich, 2015; Costa et al., 2015; Chiba, 2015 and Alfieri et al., 2016.

Throughput analysis is one of the performance indicators of discrete event simulation that uses a buffer system, as mentioned in Hema et al., 2022; Vidanelage et al., 2020; and Prasad et al., 2019. Applying this analysis can help compare the possible scenarios and provide the best action plan.

Operation time analysis that was proposed by Lang et al., 2022 also applies in this study in order to define production time in the case of fixing throughput size. This study can define the time that buffers have been used to predict the actual required buffer sizes for each scenario.

4. Conclusion

In conclusion, this study introduces a plant simulation approach aimed at predicting buffer utilization for an automotive assembly line. The current analysis reveals an excess in buffer size on the assembly line, prompting the exploration of strategies to reduce buffer size, including adjustments to worker size and sequencing strategies. Employing simulation techniques, two distinct approaches, namely throughput analysis and production time analysis, are proposed. The throughput analysis seeks to identify the required buffer sizes for maximizing throughput while utilizing the total available time. On the other hand, the production time analysis focuses on determining the time required for utilizing each buffer space while maintaining a fixed throughput size. The results underscore that the sequencing strategy involving the production of two normal models and one new model presents the optimal scenario for implementation. Without increasing worker size, this strategy efficiently concludes 48 cars per shift, utilizing 8 buffer spaces. With the addition of one worker, the throughput for this strategy increases to 58 cars per shift. Furthermore, this simulation model emphasizes the significance of the modified Blocking After Station (MBAS), which not only defines buffer usage but also outlines buffer requirements.

This research introduces a valuable simulation approach for predicting buffer usage and requirements, enabling the formulation of action plans for unfamiliar tasks within the automotive assembly line context. A sequence strategy that produces a higher ratio of normal product to new product can fix the problem of over-buffer usage immediately. This can help some manufacturing industries, especially assembly lines, that have the same problem find the solution by finding the ratio. In addition, MBAS can be another simulation technique that separates buffers into two types, including a fixed number of buffers and a variable number of buffers, and uses them at the same time instead of using a regular buffer object in the simulation that can define only one of them. Moreover, there are limitations that include two scopes, such as a bit of processing time to produce the new models and incorporating worker behavior.

Future research can be extending the analysis to consider multiple conflicting objectives, such as minimizing buffer size, reducing production downtime, and optimizing resource utilization simultaneously. In addtion, the impact of human factors can be explored, such as worker fatigue, skill levels, and ergonomic considerations, on buffer utilization and assembly line performance.

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