Modelling an Automobile Assembly Layout Plant Using Probabilistic Functions and Discrete Event Simulation

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Abstract

This study analyzed the problems faced by the assembly line of an automotive manufacturing company, which recorded an increase in the company's production cost each month. The increasing production cost incurred because the company could not satisfy the production volume target set by the production planning department. Hence, the workers needed to do extra work to achieve the goal that led to additional production costs and loss of sales. Therefore, the objective of this study is to propose a new assembly plant layout to minimize the average waiting time and average total processing time in the system and maximize the total number of completed jobs. A Discrete Event Simulation (DES) model is used as a planning tool for solving the problem under study. The performance of the proposed assembly plant layout is compared with the existing assembly plant layout using Arena software. The average waiting time, average total processing time in the system and the total number of completed jobs that will contribute to overall production costs used as performance measures. The proposed assembly plant layout shows that the average waiting time decreased by 60.61 %. The average total processing time in the system decreased by 35.12 %. The total number of completed jobs has increased by 11.23 % as compared with the current assembly plant layout. Hence the new proposed assembly plant layout is recommended.

Keywords
Arena simulation, Assembly plant, Automotive industry, Waiting time, and Total processing time

1. Introduction

In the current competitive environment, manufacturing companies, especially in the automotive industry, should improve productivity. They should fully utilise their resources (workforce, tools, machines, raw materials, etc.). In automotive manufacturing companies, the management should plan, schedule and monitor carefully the workforce needed for each workstation and all material handling in the production system to ensure a smooth production flow.

In the past decade, the manufacturing industry has experienced a dynamic revolution. Due to the complexity of the interrelationship between factors affecting the production process and company requirements, simulation methods have been widely used to solve various problems in the manufacturing industry, especially assembly plant problems. Simulation is a technique used to imitate the actual operations of a real system. It is used to help the decision-maker to understand the behaviour of the system and implement necessary improvements. According to Choong-Yeun et al. (2016), there have been various studies conducted in various areas using simulation approaches to solve problems in the manufacturing, food processing (Malekjani and Jafari, 2018; Faria et al., 2019), transportation, health care (Chraibi et al., 2016; Arnolds et al., 2012), military and other industries. Simulation has become a widespread technique in assessing the impact of decisions made in any sector. Simulation techniques presently are widely used in combination with Operation Research and Artificial Intelligence approaches in helping the decision-maker to identify the problems in the system and evaluate various alternatives for system improvements before making decisions.

In the manufacturing industry, simulation has been widely used to solve many problems such as resource planning, worker scheduling, material handling process, performance improvements, and others. Kaylani and Atieh (2016) enhanced the production scheduling procedures using a simulation approach in pharmaceutical companies with large product mixes. They assessed the performance of a schedule by measuring resource utilisation, identifying bottlenecks, throughput, and evaluating the impact of each item in the product mix. Simulation approaches were also used in workforce scheduling (Alwadood and Rani, 2010; Rani et al., 2014; Nawawi et al., 2015; Bouajaja et al., 2016). In 2015, Maram et al. used the Discrete Event Simulation (DES) model in planning a job-shop environment by using Arena simulation software. El-Khalil (2015) conducted a simulation study for managing and improving productivity in an automotive company. In 2016, Choong-Yeun et al. conducted a study to improve the performance of chilli sauce manufacturing by using a simulation approach. Jilcha et al. (2015) measured the performance of workers and machines in manufacturing systems using simulations. In determining the optimal layout design, Yemane et al. (2017) used different simulation software (Arena, AutoCAD, and POM software) to optimise the layout by improving the line balancing of a textile company. A new layout model has been proposed by Nallusamy (2016) to improve the total completed jobs and reduce lead time in a small-scale manufacturing unit. The proposed new layout successfully increased the overall productivity. Based on recent studies, simulation has proven to be a valuable tool for exploring complex problems. Thus, the simulation method is implemented to solve the problem in this study.

This study is conducted at one of the vehicle assembly plants in Melaka. A vehicle assembly plant is a factory where all the major and minor components of a vehicle are put together. Processes in a vehicle assembly plant include assembling and welding the loose components together, and inspecting the structure of the welded components. The operation times are highly dependent on the loading and unloading of raw materials and finished products from the previous workstation. This study only focused on the production and assembly line. The system studied consisted of several robotic spot-welding stations and loading and unloading stations for the assembly line. One of the typical problems in an assembly plant is to minimise the average waiting time and average total processing time in the system as well as to maximise the total number of completed jobs. Hence the objective of this study is to propose a new assembly plant layout that minimises the average waiting time and average total processing time in the system as well as to maximise the total number of completed jobs.

2. Data setting

This study is conducted in a company located in Melaka that manufactures and sells automotive components such as cross member, subframe, dash panel, door panel, etc. The company is fully equipped with a high technology facility to ensure that they can satisfy all the demand for each product and produce high-quality automotive components. The company has two assembly plants which include welding and in-house repair and maintenance. The welding assembly plant has 16 lines in total to ensure a smooth production flow. There are two types of assembly lines which include fixed jigs and flexible jigs. Fixed jigs mean that all the jigs are fixed on the floor, and the lines will produce the same product. Fixed jigs are located in welding assembly Line 01 to Line 04. Flexible jigs (welding assembly Line 05 to Line 16) means the jigs are interchangeable and the workstation can produce more than one product. The flexible jigs require two hours of setup time. Due to the complexity and lengthy-time required to set up a flexible jig, this study is limited to the fixed jigs and focuses on Line 03. Based on the observation during a site visit, Line 03 has a longer processing time, which leads to low productivity. Thus, Line 03 is chosen in this study to identify the problems and come up with necessary improvements.

Line 03 consists of two different stations, i.e. the right station (RH-STN) and the left station (LH-STN). There are three spot welding robots, four workers, and five fixed jigs each at RH-STN and LH-STN. It produces Frame Comp R Rear and Frame Comp L Rear. The attributes of Line 03 are summarised in Table 1. There are five fixed jigs each installed at RH-STN and LH-STN. Each workstation is responsible for a single type of assembly product. Next, Table 2 below shows the type of product produced by Line 03 and its capacity. The capacity is based on 10 hours per production shift.

Table 1: The attributes of Line 03

Line	Robotic Spot Welding	Number of Workers	Number of Jigs	
			Right	Left
03	3	4	5	5

Table 2: Type of Product and Capacity

Line	No	Item	No. of Item per Shift
L03	1	Frame Comp R Rear	120
	2	Frame Comp L Rear	120

2.1 Production process

The actual working time for the company is 10 hours of production time per day. Before starting the daily production, a start-up or inspection activity will be conducted by all the workers in each line. This inspection is monitored by a team leader and line keeper to ensure that all items are functioning correctly. The inspection process takes about 10 to 15 minutes daily before the production starts. Each product has a different production process. The products go through a different process due to the different requirement for each side of the product. The capacity and time taken to produce each product is similar due to the similarities between the right and left sides of a car. For instance, the total time and capacity to produce Frame Comp R Rear is similar to Frame Comp L Rear even though it has a different process. The different total time for different processes and the different requirements for each side of the product do not affect the total time of production. Therefore, the product quantity produced within 10 hours of production is similar. The details of the production process for each product in Line 03 is shown in Figure 1. There are five jigs (Jig #100, Jig #200, Jig #300, Jig #400 and Jig #500) available at both RH-STN and LF-STN. There is only one worker at the starting point of Line 03, a worker at RH-STN and LF-STN to handle all the jigs at the respective stations and one worker at the quality gate at RH-STN and LF-STN.

The RH-STN produces Frame Comp R Rear, and the LF-STN produces Frame Comp L Rear. These two different products require the same number of processing stages. Each stage is conducted at a different workstation. The production starts at the first workstation (Jig #100) and needs to pass through all the jigs at their respective workstations. There are two main tasks at each stage:

i. The first task is the process of loading and unloading the sub-assembly product from the jig, and sending the finished sub-assembly product from one workstation to another workstation. The first task is done manually by the worker.
ii. The second task starts with the clamping and welding process of spot points needed, which is conducted by robots. As these processes finish, the clamp will open automatically, and the sub-assembly product will be unloaded from the jig.

The processing time for each stage is recorded. These processes are repeated at the next workstations until all the number of spot points needed are reached. Later, the finished products will undergo an inspection process by a worker at the quality gate to ensure that all the spot points required are in good condition and to ensure the clamping process is done correctly. Then, the product will be packed in batches of 30 units each and sent to the warehouse before delivery.

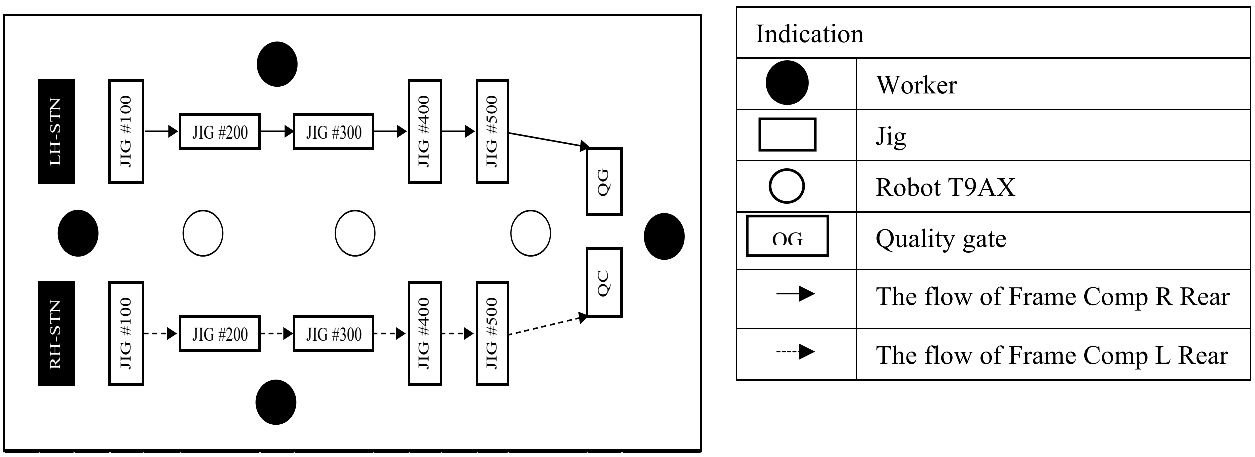

Figure 1: Assembly Plant Layout

Table 3 summarises the sequence of the production process and the number of spot points needed at each jig as well as the processing time of Frame Comp R Rear and Frame Comp L Rear.

Table 3: Job Specifications

Job	Type of Job Produced	Production Sequence	Number of Spot Points Needed	Average Processing Time (second)
1	Frame Comp R Rear	Jig #100	14	26.7
		Jig #200	15	41.7
		Jig #300	15	28.7
		Jig #400	14	65.0
		Jig #500	19	64.0
		Quality Gate	76	434.3
2	Frame Comp L Rear	Jig #100	13	71.3
		Jig #200	15	31.3
		Jig #300	18	72.7
		Jig #400	14	72.0
		Jig #500	16	75.3
		Quality Gate	76	434.3

In this study, the input data is obtained through direct observation. The process involved in Line 03 is observed for three days, starting from 8 a.m. to 6 p.m. The input data, such as material handling by workers and robots for each workstation, are collected and recorded. Material handling time by worker refers to the time for loading and unloading the product from the jig and sending the finished product from one workstation to another workstation. Material handling time by robot refers to the time for the welding and clamping process at each workstation. The use of the input data in the model involves specifying the theoretical distribution in the simulation process. Arena Input Analyser is used in this study to determine the theoretical distribution of each data due to its capability to identify various types of distribution (Alwadood and Rani, 2010). These parameters are shown in Table 4:

Table 4: The probability distribution function for material handling by worker and robot

Jig	**Task**	**Probability Distribution Function**	
		Right Station	**Left Station**
100	Material handling by worker	302+42*BETA (0.265,0.194)	312+40*BETA (0.421,0.336)
	Material handling by robot	POIS (26.7)	POI (25.5)
200	Material handling by worker	10.5+14*BETA (0.475, 0.328)	15.5+7*BETA (0.818, 0.781)
	Material handling by robot	TRIA (45.5, 46, 46.5)	TRIA (30.5, 31, 32.5)
300	Material handling by worker	15.5+7*BETA (0.671, 0.463)	29.5+54*BETA (0.263, 0.333)
	Material handling by robot	TRIA (27.5, 29 ,29.5)	TRIA (71.5, 73, 73.5)
400	Material handling by worker	15.5+15*BETA (0.072, 0.0659)	13.5+8*BETA (0.615, 0.699)
	Material handling by robot	UNIF (63.5, 66.5)	64.5+WEIB (8.18, 0.441)
500	Material handling by worker	4.5+6*BETA (0.776, 0.825)	4.5+6*BETA (0.776, 0.825)
	Material handling by robot	TRIA (65.5, 67, 67.5)	UNIF (73.5, 77.5)
Quality Gate	Material handling by worker	UNIF (9.5, 12.5)	UNIF (9.5, 12.5)
	Inspection process by worker	100+WEIB (0.913, 0.181)	180+WEIB (0.913, 0.181)

3. Modelling assembly line

Simulation is the most suitable method to analyse the problem under this study, due to the complexity of the interrelationship between factors affecting the determination of capacity requirements in an assembly plant problem. Moreover, the ability of a simulation model to help understand the possible effects to avoid possible risks before implementing a decision in a real system, makes it the most suitable method to be used in this study.

In this study, the assembly plant layout simulation model is developed for Line 03. The actual simulation is modelled using Arena simulation software, shown in Figure 2. In Arena, the Frame Comp R Rear and Frame Comp L Rear are represented by Entity 1 and Entity 2 respectively, and the production line process or equipment are represented by predefined modules. For example, 'Create Module' is the starting point for entities in the Arena simulation model. The time between assembly product arrivals follows the distribution function, as mentioned in Section 2.1 (Table 4). The entities then enter the 'Process Module' and wait in sequence at the respective 'Station Module' until all specific resources are available for the clamping and welding process conducted by a robot. The clamping and welding process at the 'Station Module' will start based on their arrival times or a first-come, first-served basis. The entities move to the next workstation through the 'Route Module'. These processes are repeated at the next workstations. The entities would then undergo the next 'Process Module' for quality check. In the last step, the entities would go to the last '2-way by Chance Decide Module' to determine if the end product of the assembly products meets all the requirements needed by the company. If the assembled product meets the company standards, it will leave the system, and if not, it will be sent to the first station for a rework process. The simulation is run for 10 hours to obtain performance measures. The average total time in the system and the total number of completed jobs are recorded.

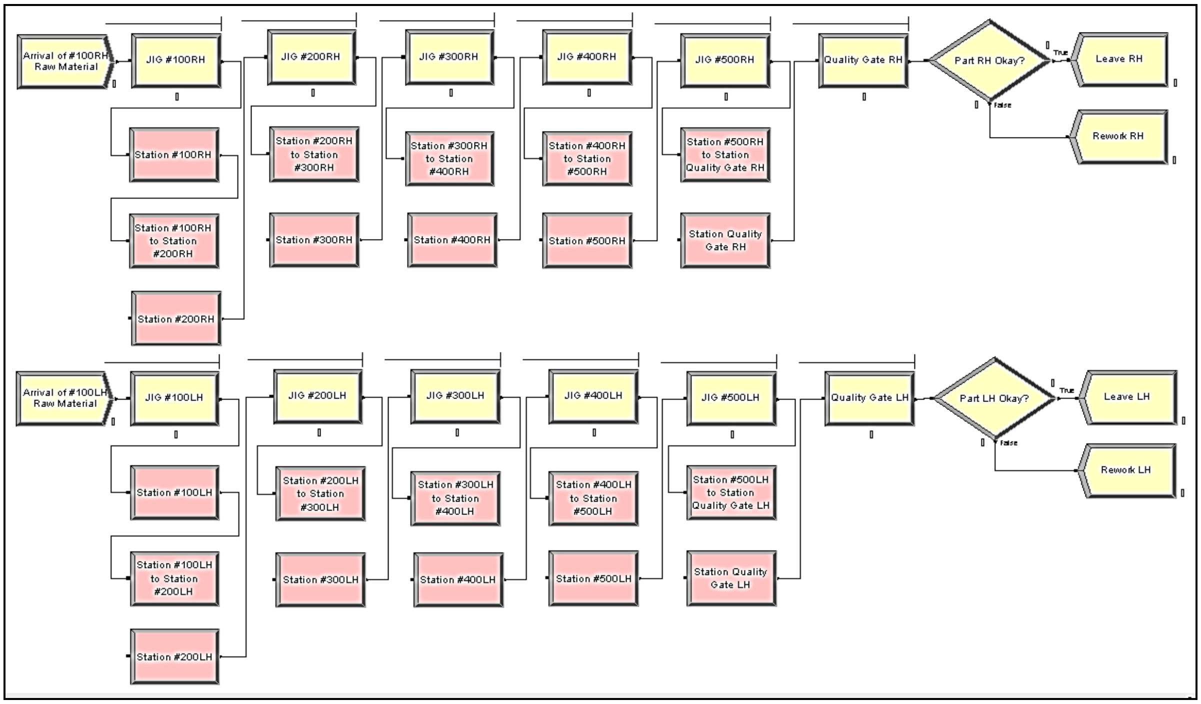

Figure 2: Simulated Assembly Plant Layout using Arena

3.1 Model output

After developing the simulation model, the model is run for eight hours in 10 replications. Then, the actual simulation model output is used to measure the effectiveness of the proposed assembly plant layout by considering the average waiting time, the average total processing time in the system and the total number of completed jobs. The simulation's output and the real data are used in this stage for verification and validation purposes.

3.2 Model verification and validation

The next step is model verification and validation. The purpose of the model verification and validation is to ensure that the simulation model reflects the real system (Stevenson and Ozgur, 2007).

3.2.1 Model verification

Model verification is the process to ensure that the simulation model represents the real system (Kaylani and Atieh, 2016). In this study, the model verification is done by using Little's formula as in equation 1(Jilcha et al., 2015):

$$\bar{N} = \lambda \bar{W} \tag{1}$$

Where $\bar{N}$ refers to the average number of entities in the system, λ refers to the average arrival rate of entities in the system and $\bar{W}$ the average time of entities in the system.

In this study, $\bar{N}$ refer to the average number of Entity 1 (6.2471 units) and Entity 2 (8.3599 units) in the system. λ is the average arrival rate for Entity 1 and Entity 2 in the system. The average arrival rate, λ for Entity 1 equals to 0.0031, $\left(\lambda = \frac{111}{36000}\right)$ and the average arrival rate, λ for Entity 2 equals to 0.0030, $\left(\lambda = \frac{108.4}{36000}\right)$. $\bar{W}$ = 1870.99 and 2716.27 for Entity 1 and Entity 2 respectively refer to the average time of entities in the system. Thus, $\lambda\bar{W}$ equals to 5.8001 for Entity 1 and $\lambda\bar{W}$ equals to 8.1488 for Entity 2. Little's formula shows that the simulation model is free from any error and represents the actual system.

3.2.2 Model validation

Model validation is the process to make sure that the simulation output closely approximates the performance of the real system. Model validation process could be done by comparing the output of the simulation model to the output of the actual system by using the formula in (2):

$$\text{Difference (\%)} = \frac{|\text{simulation output} - \text{actual data}|}{\text{actual data}} \times 100\% \qquad (2)$$

Based on the formula above, simulation output refers to data from the simulation model, and actual data refers to the data from the real system. According to Choong-Yeun et al. (2016) and Anderson et al. (2005), the difference should be less than or equal to 10% in order to consider that the simulation model has achieved sufficient accuracy compared with the actual system.

Table 5 shows the time difference (in percentage) between actual data and simulated output for each stage of Entity 1 and Entity 2. The table clearly shows that the average time difference per entity equals to 1.1911 % and 0.7263 % for Entities 1 and 2, respectively. Meanwhile, Table 6 shows the number of Entity 1 and Entity 2 entering and leaving the system. The difference in the percentage of the entity entering the system for Entity 1 and 2 are 7.5 % and 10%, respectively. In contrast, the difference in the percentage of entity leaving the system for Entity 1 and 2 is 2 % and 9 %, respectively. It clearly shows that all the percentage differences are less than 10 %. These results prove that the simulation model is a good representation of the real system and the simulation model is valid.

Table 5: The comparison of time per entity between simulation output and the real data for each stage of Entities 1 and 2

Entity	Stage	Simulation Output (seconds)	Actual data (seconds)	Difference (%)
1	Jig #100	26.7927	26.0000	3.0488
	Jig #200	45.9959	46.0000	0.0089
	Jig #300	28.6704	29.0000	1.1366
	Jig #400	64.9309	67.0000	3.0882
	Jig #500	66.6662	67.0000	0.4982
	Quality Gate	210.4700	240.0000	0.2238
	Total Average	90.2288	89.1667	**1.1911**
2	Jig #100	25.4862	28.0000	8.9779
	Jig #200	31.3367	34.0000	7.8332
	Jig #300	72.6835	75.0000	3.0887
	Jig #400	84.8246	77.0000	8.7495
	Jig #500	75.4664	75.0000	0.6219
	Quality Gate	297.0100	300.0000	0.9967
	Total Average	98.8797	98.1667	**0.7263**

Table 6: The comparison between simulation output and real data for the number of entities entering and leaving the system for Entities 1 and 2

Entity		Simulation output (unit)	Real data (unit)	**Difference (%)**
1	Number of entities entering the system	111	120	**7.50**
	Number of entities leaving the system	102	100	**2.00**
2	Number of entities entering the system	108	120	**10.00**
	Number of entities leaving the system	91	100	**9.00**

3.3 Proposed plant layout

In this study, the proposed assembly plant layout simulation model is developed for Line 03 to minimise the average waiting time, average total processing completion time in the system, and maximise the total number of completed jobs. The current assembly plant layout has been modified by increasing the number of quality gate stations from two to four and placing an inspection quality at each quality gate, as shown in Figure 3. The simulation is run for 10 hours to obtain performance measures. The average waiting time, the average total processing time of service in the system, and the total number of completed jobs are recorded.

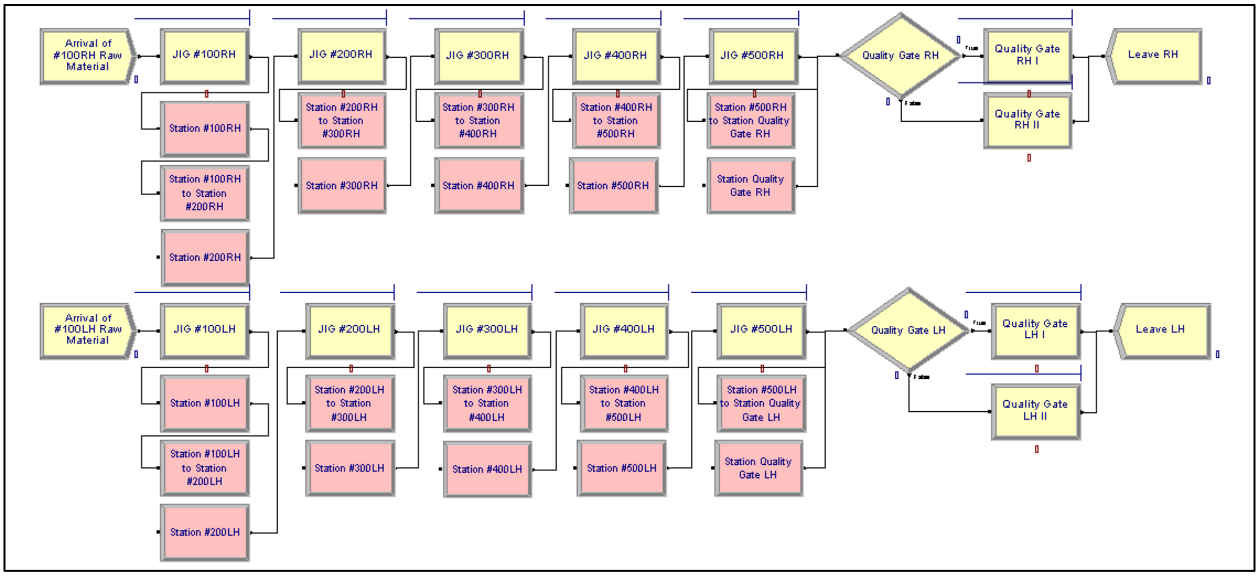

Figure 3: Simulated Assembly Plant Layout using Arena (Proposed Model)

4. Results and Discussion

After the simulation results are validated, the simulation model is used to analyse and improve the production line process. The average total time in the system and the total number of completed jobs between simulated and actual data are compared in the following section.

4.1 Actual Simulation Results

The simulation results are shown in the following table. Table 7 shows the average waiting time, average processing time per Entity, and average total processing time in the system for Entity 1 and Entity 2, respectively. Table 7 clearly shows the average waiting time for quality check at the quality gate for Entity 1 (1346.5847 seconds) and Entity 2 (2024.0933 seconds). The average processing time per Entity refers to the time taken to complete the process of producing one unit of product per day. The average total processing time equals 1790.1108 seconds and 2610.9030 seconds for Entity 1 and Entity 2, respectively. The average total processing time is the time taken to complete the process of producing the products per day. As mentioned before, the quality check at the quality gate is done manually, which leads to the higher waiting time at this process.

Table 7: Average waiting time, and average total processing time for each process for Entities 1 and 2

Entity	Stage	Average Waiting Time (second)	Average Total Processing Time (second)
1	Jig #100	2.6496	29.4423
	Jig #200	3.5695	49.5654
	Jig #300	29.9414	58.6118
	Jig #400	30.8137	95.7446

	Jig #500	3.1005	69.7667
	Quality Gate	1276.5100	1486.9800
	Total Average	**1346.5847**	**1790.1108**
2	Jig #100	4.2799	29.7661
	Jig #200	6.4745	37.8112
	Jig #300	18.3040	90.9874
	Jig #400	14.8930	99.7200
	Jig #500	0.1519	75.6183
	Quality Gate	1979.9900	2277.0000
	Total Average	**2024.0933**	**2610.9030**

4.2 Proposed Simulation Results

Based on the simulation results discussed earlier, the weakness of the current system is at the quality gate where the inspection process takes place. It clearly shows that the average waiting time at the quality gate for both products is quite large as compared to the other processes. As mentioned earlier, the inspection process is performed manually by a worker at each workstation. Hence, some improvements are suggested to the management to reduce the average waiting time at the quality gate for both products by modifying the production plant using a simulation model. The impact of the modification can be directly observed through the simulation results.

The proposed simulation results are shown in Table 8. The results clearly show the average waiting time, average processing time per Entity, and average total processing time in the system for Entity 1 and Entity 2, respectively. Both tables clearly show that the average waiting time at the quality gate has decreased to 11.2025 seconds from 1276.5100 seconds for Entity 1, while the waiting time for Entity 2 at the quality gate has decreased to 5.9646 seconds from 1979.9900 seconds. The average waiting time for Entity 1 is 66.5974 seconds, and Entity 2 is 41.3303 seconds. The average total processing time equals to 843.3329 seconds and 869.8089 seconds for Entity 1 and Entity 2, respectively. The details of the comparison between the actual simulation model and the proposed simulation model are discussed in the following section.

Table 8: Average waiting time and average total processing time for each process for Entities 1 and 2 (Proposed Simulation)

Entity	Stage	Average Waiting Time (second)	Average Total Processing Time (second)
1	Jig #100	2.6704	29.4107
	Jig #200	3.4534	49.4443
	Jig #300	22.6173	51.2738
	Jig #400	23.7632	88.7779
	Jig #500	2.8906	69.5462
	Quality Gate I	10.5540	281.0600
	Quality Gate II	0.6485	273.8200
	Total Average	**66.5974**	**843.3329**
2	Jig #100	5.4116	30.8877
	Jig #200	5.8486	37.1867
	Jig #300	13.5681	86.2241
	Jig #400	10.4012	92.7426
	Jig #500	0.1362	75.5888
	Quality Gate I	5.9646	276.0900
	Quality Gate II	0.0000	271.0900

Total Average	**41.3303**	**869.8099**

4.3 Comparison Results

Table 9 shows the comparison of the simulation's output between the actual and proposed simulation model of the assembly plant. It clearly shows that the addition of two quality gate stations at the right and left workstations has significantly reduced the waiting time and average total processing time for both products. However, the overall effect on average processing times is slightly reduced.

Table 9: Average waiting time, average total processing time and total time for each process for Entity 1 and Entity 2

		Actual Simulation	Proposed Simulation	**Difference (%)**
Average Waiting Time (second)	Entity 1	1346.5847	66.5947	**-95.0545**
	Entity 2	2024.0933	41.3303	**-97.9581**
Total Average		3370.6780	107.9250	**-193.0126**
Average Processing Total Time (second)	Entity 1	1790.1108	843.3329	**-52.8893**
	Entity 2	2610.9030	869.8099	**-66.6855**
Total Average		4401.0138	1713.1428	**-119.5748**

Table 10 shows a comparison of the total number of completed jobs per shift between the actual simulation and the proposed simulation model. By looking at the simulation result, it clearly shows that the proposed assembly plant layout (proposed simulation), shows the highest number of completed jobs per shift with an additional 7 and 15 units for Entities 1 and 2, respectively. Specifically, the total number of completed jobs for Entity 1 would be increased by 6.6827 % as compared to the current assembly plant layout. In contrast, the number of completed jobs for Entity 2 has increased by 16.4835 %.

Table 10: Comparison of the total number of completed jobs per shift between Simulated and Actual Data.

	Actual Simulation	Proposed Simulation	**Difference (%)**
Entity 1	102	109	**6.8627**
Entity 2	91	106	**16.4835**
Total	193	215	**23.3463**

5. Conclusions

By looking at the actual simulation result, it is identified that the company fails to meet its required volume per shift due to the highest average waiting time at the quality gate station compared to other workstations. The workers need to do extra work to achieve the required volume. This situation leads to a higher production cost for the company. Therefore, this study proposed a modification of the assembly plant layout. The current assembly plant layout has been modified by increasing the number of quality gate stations from two to four in order to reduce the waiting time at the quality gate and to maximise the volume of production per day. Simulation runs are performed on the proposed assembly layout in this study. The average waiting time, average total processing time in the system and the production quantity from the proposed alternative is compared to the current situation. The simulation results show that the new proposed assembly plant layout has reduced the waiting time at the quality gate station and average total processing time for both products, as presented in Table 9. Additionally, the production has also shown a slight increase in both products, as presented in Table 10. Therefore, the company would be strongly recommended to go for this proposed assembly layout. The acceptance or rejection of this recommendation depends on the company's policies and its capital. If the company accepts this proposed assembly layout, the average waiting time and total average processing time would be reduced and hence, the penalty cost incurred could be significantly reduced.

Nevertheless, the simulation model in this study did not consider uncertainty factors such as machine breakdown time, rework process due to technical errors during the production process, costs related to the operations, and workers' capability. These issues can be considered in future studies for each operation, and solutions can be proposed to improve the overall production process.

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