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LINE BALANCING IMPROVEMENT IN THE WELDING SECTION OF A CAR ASSEMBLING PLANT

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Abstract. This paper presents a case study on a line balancing problem in a car assembling plant. This study was aimed at providing alternatives in reducing current problems at the H-N welding line of the body assembling section in the plant. Investigation was conducted to identify causes for bottlenecks that resulted in low productivity level and high resource wastage. Using the results of unstructured interviews, time study data and observations on the process, the problem was analysed and the main causes identified were unbalanced line and poor material handling system. To improve the current situation, alternatives were generated using line balance technique. QUEST, which is a 3D digital factory simulation software, was used in the analysis of the alternatives. The process was modelled using QUEST and simulation was conducted on the current system and also several possible alternatives. The results of the simulation studies were analysed and evaluated before the best alternative is selected and proposed. The paper culminates with a proposed solution to improve line balancing at the selected welding operations in the company.

Keywords: Line balancing, productivity improvement, simulation

Abstrak. Kertas kerja ini membentangkan kajian kes masalah imbangan lini di kilang pemasangan kereta. Kajian ini bertujuan menyediakan alternatif dalam mengurangkan masalah semasa di lini kimpalan H-N bahagian pemasangan badan di loji tersebut. Kajian dilakukan untuk mengenal pasti *bottleneck* yang mengakibatkan tahap produktiviti rendah dan pembaziran sumber yang tinggi. Dengan menggunakan keputusan dari temubual tidak berstruktur, data kajian masa dan pemerhatian proses, masalah dianalisis dan punca utama yang dikenalpasti adalah ketidak seimbangan lini dan sistem pengendalian bahan yang kurang baik. Untuk mengatasi keadaan ini, beberapa alternatif telah dibentuk melalui teknik imbangan lini. QUEST iaitu perisian simulasi 3 dimensi kilang digital telah digunakan untuk menganalisis alternatif-alternatif tersebut. Proses telah dimodel mengunakan QUEST dan seterusnya simulasi dilakukan untuk keadaan semasa dan beberapa alternatif. Keputusan dari kajian simulasi dianalisis dan dinilai sebelum alternatif terbaik dicadangkan. Kertas kerja ini diakhiri dengan satu cadangan penyelesaian untuk membaiki imbangan lini di operasi kimpalan yang dipilih di syarikat tersebut.

Kata kunci: Imbangan lini, peningkatan produktiviti, simulasi

1.0 INTRODUCTION

In this era of globalization, competition is becoming ever more intense. Manufacturing companies must not only compete locally but also on a global basis. Reducing

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manufacturing costs without sacrificing product quality is vital for the survival of manufacturing companies in a global market. The automotive industry is not spared from the effects of globalization. The local Malaysian automotive manufacturers are faced with this tough competition as the selling price is not much different from foreign brands especially with the implementation of the ASEAN Free Trade Area (AFTA). Demand for foreign cars will probably soar; more so for cars that are assembled locally as the price becomes cheaper. Increasing productivity will be important to ensure survival of the numerous players in the automotive sector. Late delivery of cars due to low productivity can cause companies losing customers as well as resulting in dissatisfaction.

One of the ways to improve productivity is through Industrial Engineering (IE). Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy [1]. It draws upon specialised knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems. Some of the commonly used tools to solve productivity problems in IE include work study, line-balancing, quality control, production planning and control, simulation, facility planning, and others [1]. These techniques are aimed at achieving smooth and undisrupted factory operation, increasing efficiency and effectiveness through better utilization of resources.

The processing capability of computers have increased by leaps and bounds over the past decades. Together with the improved visualisation capabilities of graphic processing units, complex computer generated graphics, more and more software applications dedicated for solving industrial problems are available in the market [2]. The use of simulation software to analyze problems as well as to generate alternatives has risen significantly. Realizing the potential benefits of computer simulation in a manufacturing environment, a 3D commercial software by Delmia called Queuing Event Simulation Tool (QUEST) was used in this study.

This paper presents a case study of productivity improvement in a car assembly plant by identifying causes of productivity problems, and to demonstrate the use of QUEST in evaluating improvement alternatives. The analysis and evaluation of these alternatives were conducted based on the outputs obtained from the simulation models. This paper begins with a brief description of the case study company and followed by problem identification and descriptions of the problems. Based on the problems identified, the construction of the alternative solutions as well as the simulation methodology are discussed. This is followed by discussions of the evaluation results and culminates with conclusions drawn from the findings of this study.

2.0 COMPANY PROFILE

This study was conducted at a local automobile assembling factory which specialises in the assembly of foreign cars using imported completely knocked down (CKD) parts. The company is not engaged in research and design activities, but does engine assembling, as well as in-house jigs and fixtures manufacturing. The company was established in 1967, and currently employs 550 workers. The plant's production capacity is around 2000 units per month. Previous studies have looked at different aspects and different sections of the company [3, 4]. This study focused on the floor complete subassembly at the H-N welding line in the body assembling section. It is a continuation of previous studies conducted at this company

2.1 Manufacturing Process

The company adopts a process layout in its factory layout design. The major departments involved in the car assembly process are the body shop, paint shop, final assembly line and final inspection. The welding processes of the floor complete subassembly is as follows and details are given by Chin [5]:

(i) The front floor, rear floor and centre floor are welded in individual weld stations first (FRT FLR, CTR FLR, RR FLR stations respectively).
(ii) Parts are then sent to respective respot stations where additional spot welds are done.
(iii) Parts are then transferred to FC weld station to be welded into the floor complete subassembly or the chassis for the main body of a car.

Almost all material handling between stations are done manually, except for the transfer between FRT FLR and FRT FLR respot stations, and between FRT FLR respot and FLR COMPLT stations where an overhead hoist is used.

3.0 PROBLEM IDENTIFICATION

The next step in this project involved identifying the problems that occurred in the selected production line. Selected IE tools and techniques together with the basic problem identification methodology were employed. The outline of the problem identification methodology employed can be seen in Table 1.

The problem identification process indicated that the welding line is experiencing excessive idle time where operators are idle on almost every production cycle. The possible causes for the excessive idle time are the varying operator skill level, inadequate welding gun maintenance, uneven job distribution, and manual handling of materials. The unbalanced line due to the uneven job distribution between stations is identified to be the major cause of high idle time of operators in the welding line.

Table 1 Problem identification methodology

Step	Main activities
1.	Background study: Reference materials are company documents including operation standards, plant layout, production schedule and process flow chart. Discussions with Engineering Manager provided basic knowledge on the operations in the line, the material flow, and the parts involved.
2.	On-site observation: Observations covered the aspects of operators, machines and equipments, working environment and the material used for the welding process involved.
3.	Unstructured interviews: Through interview sessions, various opinions and views from different perspective and level of expertise of the interviewees were obtained. Conducting interviews with these operators and line leaders ensured the problem identification to be open minded and was not biased.
4.	Data collection and analysis: The data collected include the production rate, line layout, quality inspection report and standard time on welding operations. Besides being used for analysis purposes, the data collected was also used for simulation model building. The Cause and Effect (CE) diagram is used to identify possible causes to the problem faced in the production floor.

In order to determine the operation time for each work element performed by operators in the welding stations, direct time study was conducted on these operations. The results of the study indicated that the line is unbalanced as some of the stations finished their work earlier than others and the station with the long cycle time slows down the production rate and hence causes the other stations to be idle. The percentage of Line Balance Loss (%LBL) was then calculated. It was found that the %LBL of the line is 20.30% with Operators 2, 8 and 9 having working time of 10.43, 11.44 and 11.58 min respectively. They appeared to be doing more work when compared to the standard time chart shown in Figure 1. Operators 1 and 6 can handle more work than the present level. The labour assignment at each station is shown in Table 2.

A precedence diagram was constructed as shown Figure 2. Operator 2 works at Front Floor Station (Station A) while Operators 8 and 9 work at Floor Complete Station (Station G). As the cycle time for these operators appears to be higher than other operators, it is concluded that Operators 1, 3, 4, 5, 6, and 7 in stations A, B, C, D, E, and F respectively are idle during each process cycle while waiting for the subsequent stations to complete their job.

It is concluded that the welding line is unbalanced since some of the operators are overloaded while others are assigned with lesser work. This in turns result in variation of actual process times and caused operators to be idle in some work stations. In order to minimise operators' idle time, corrective actions should be taken to balance the line.

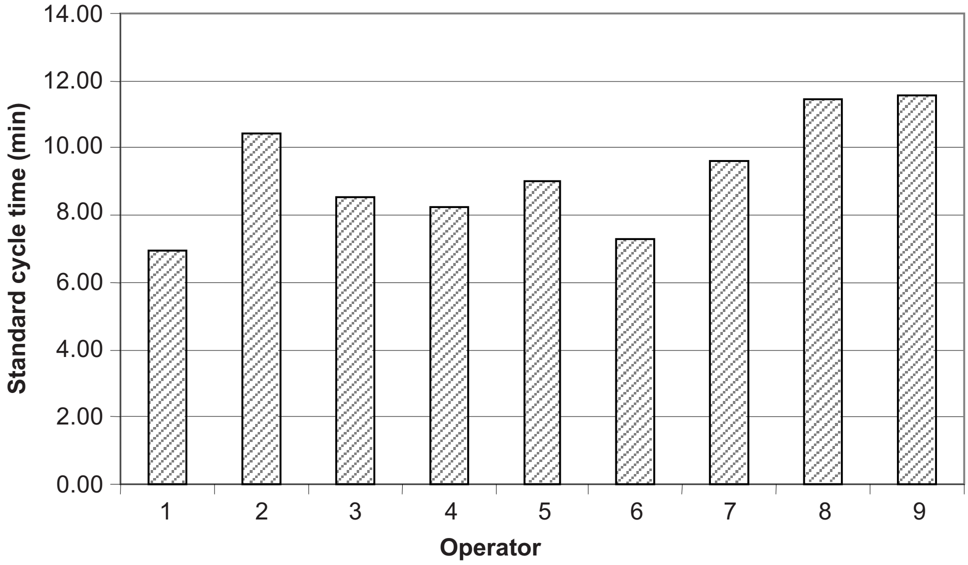

Figure 1 Standard cycle time for each operator

Table 2 Labour assignment in welding stations

Code	Station name	Labour assignment
A	Front floor	1, 2
B	Front floor respot	3
C	Centre floor	4
D	Centre floor respot	5
E	Rear floor	6
F	Rear floor respot	7
G	Floor complete	8, 9

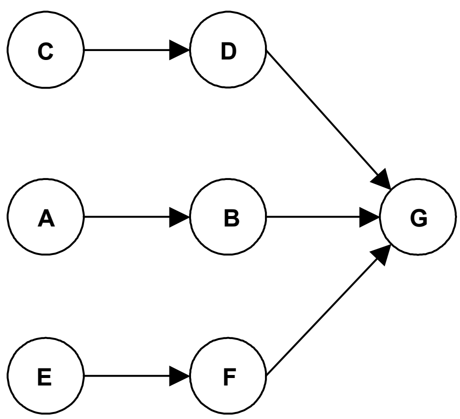

Figure 2 H-N welding station precedence diagram

4.0 PROPOSED IMPROVEMENT ALTERNATIVES

As the unbalanced welding line is identified as the main cause for high operator idle time during production, line-balancing techniques are used to develop alternatives to study this problem. Apple [6] proposed six methods to help attain balanced line and some were considered when developing the alternatives. The six methods are:

(i) Building up banks of materials
(ii) Moving or shifting operators
(iii) Grouping or subdividing work elements
(iv) Improving the operation
(v) Improving operator performance
(vi) Having the operator to work on subassemblies during available time

4.1 Alternative 1: Increase Work in Process (WIP) Storage Size

As for the WIP storage size at the work stations, it was found that some work stations do not even have WIP storage. The first alternative suggested is to install WIP storage on some of the stations. Table 3 shows the current WIP storage space, the proposed additional storage space to be added and WIP storing method. The WIP storage size is the maximum number of parts that a storage solution can hold.

For this alternative, it is suggested that an overhead hoist be added to stations B and E with the location of the new hoist to be installed as shown in Figure 3. Since station B already has access to a hoist, only an additional carrier with adjustable length will be added compared to station E which requires both the overhead hoist rail and carrier.

The overhead hoist was chosen as the WIP storage solution because it utilises the overhead space while freeing up valuable floor space within the clustered workspace. As the size of the parts is quite big and heavy, stacking the parts on the floor will consume floor space and restrict operator movement between stations. The low

Table 3 Proposed additional storage space to current method

Code	Station name	WIP storage size			Method
		Current	Increment	Total	
A	Front floor	1	–	1	Hung (Overhead hoist)
B	Front floor respot	1	1	2	Hung (Overhead hoist)
C	Centre floor	0	–	0	–
D	Centre floor respot	0	–	0	–
E	Rear floor	0	1	1	Hung (Overhead hoist)
F	Rear floor respot	3	–	3	Vertically stacked
G	Floor complete	3	–	3	Vertically stacked

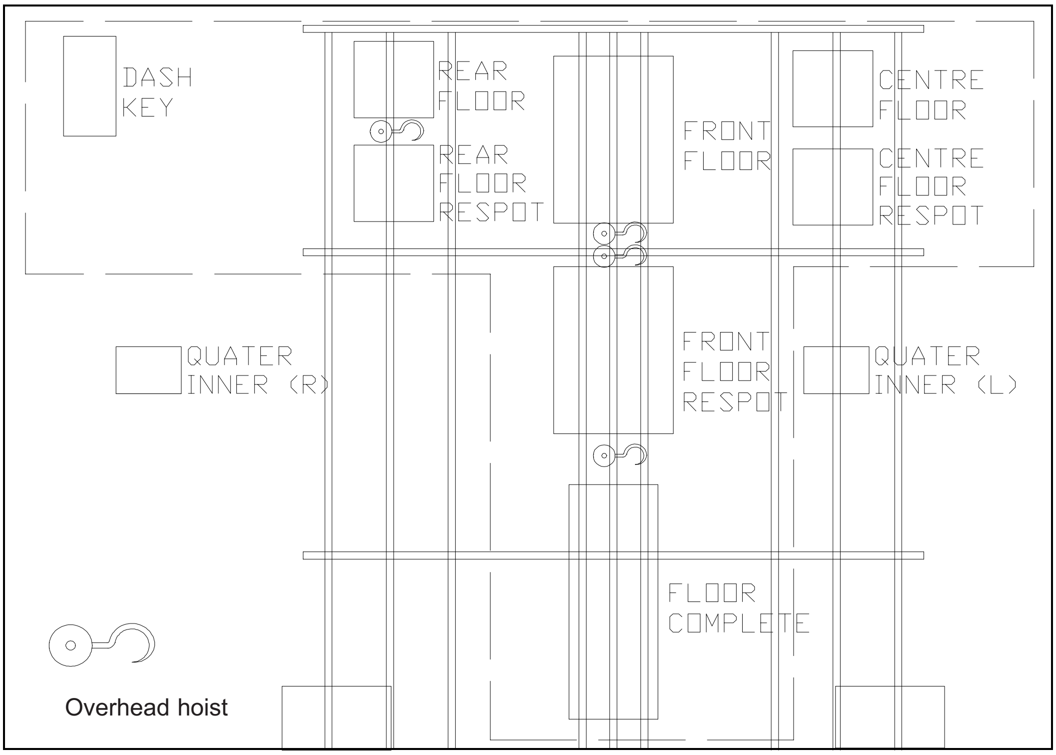

Figure 3 Location of overhead hoists in the welding line

mechanised material handling and storage solution is found to be more suitable when compared to mechanised conveyors as the parts handled are low volume, heavy, irregularly shaped and with mixed or varying sizes.

The overhead hoist does not only hold finished subassemblies in each station but it also eliminates the need for additional operator to transport the subassembly to subsequent station, for example the Rear Floor Respot Station. This is because in the current system, both operators RF and RFr are required to transfer the Rear Floor Complete subassembly manually from Rear Floor welding station to the subsequent Rear Floor Respot station.

4.2 Alternative 2: Reassignment of Work Elements

Combining and reassigning work elements to operators are aimed at achieving equal cycle time. Table 4 shows the tasks assigned to each operator for the current system and each alternative. The %LBL is calculated to estimate the line balance loss for the new tasks assignment. Modifications of the tasks assignment are focused on Operators 1, 3 and 6 only as they have shorter cycle time and therefore, high idle time. Three alternatives (2A , 2B, 2C) are suggested.

Table 4 Task assignment for current system and alternatives

Operator	1	Time	2	Time	3	Time	4	Time	5	Time	6	Time	7	Time	8	Time	9	Time	LBL
Current system	A1	45.67	B1	47.83	C1	92.80	D1	85.20	E1	15.20	F1	86.40	G1	13.20	H1	166.60	I1	156.60	
	A2	11.83	B2	8.67	C2	386.60	D2	17.00	E2	478.40	F2	6.40	G2	550.00	H2	21.40	I2	18.80	
	A3	36.17	B3	30.50	C3	28.40	D3	335.20	E3	24.80	F3	125.40	G3	2.60	H3	360.20	I3	354.60	
	A4	21.33	B4	28.83	C4	4.20	D4	18.80	E4	14.80	F4	15.20	G4	7.40	H4	40.40	I4	40.60	
	A5	11.33	B5	14.00			D5	14.80	E5	5.00	F5	12.40			H5	27.80	I5	50.40	
	A6	166.00	B6	163.17			D6	19.40			F6	8.40			H6	59.60	I6	63.80	
	A7	20.00	B7	87.67			D7	3.00			F7	137.00			H7	8.20	I7	8.20	
	A8	40.33	B8	148.00							F8	17.40							
	A9	22.67	B9	15.00							F9	9.80							
	A10	36.33	B10	82.17							F10	9.80							
	A11	4.17	B11	4.17							F11	8.20							
Total		415.83		630.00		512.00		493.40		538.20		436.40		573.20		684.20		693.00	20.21
Alt 2A											H5	50.40			(H5)	-27.80	(I5)	-50.40	
											I5	27.80							
Total		415.83		630.00		512.00		493.40		538.20		514.60		573.20		656.40		642.60	15.77
Alt 2B	(A8)	-40.33	(B6)	-163.17	B6	163.17						-436.40		-573.20					
	(A9)	-22.67			A8	40.33						479.30		479.30					
	(A10)	-4.17			A9	22.67						17.70		17.70					
Total		348.66		466.83		738.17		493.40		538.20		497.00		497.00		684.20		693.00	25.39
Alt 2C	(A8)	-40.33	(B6)	-163.17	B6	163.17													
	(A9)	-22.67			A8	40.33													
	(A10)	-4.17			A9	22.67													
Total		348.66		466.83		738.17		493.40		538.20		436.40		573.20		684.20		693.00	25.16

For alternative 2A, the elements H5 and I5 are assigned to Operator 6. Welding operations in Floor Complete station carried out by both Operators 8 and 9 will remain unchanged.

In alternative 2B, Operator 3 is loaded with job elements A8, A9 and B6. Freeing Operator 2 earlier to carry out welding processes in Dash Key station will reduce the long cycle time. In addition, Operator 1 can concentrate on welding one side of the subassembly in this new alternative instead of going around the welding station to complete the spots left by Operator 2 after work is completed at the Dash Key station. In alternative 2B, both Operators 6 and 7 will jointly carry out operations at Rear Floor and Rear Floor Respot stations. The new job distribution for both the operators is presented in Table 5. With this new work distribution, work elements F10, G1, and G4 are eliminated. In determining the cycle times for Operators 6 and 7, it was assumed that increasing the number of operators in a job originally carried out by one operator to two operators will decrease the process time by half.

As for alternative 2C, it is similar to alternative 2B only that the jobs carried out by both Operators 6 and 7 are divided equally between them while the workload for Operator 3 remains the same as in alternative 2B. This is to determine the effect of the reassignment of work elements between Operators 6 and 7.

Table 5 New job assignment and process time for Operators 6 and 7

Code	Element name	Time (sec)
F1	Load parts to jigs	43.20
F2	Clamp all units	3.20
F3	Spot weld	62.70
F4	Unclamp units	7.60
F5	Load remaining parts to jigs	6.20
F6	Clamp units	3.20
F7	Spot weld	68.50
F8	Unclamp all units	8.70
F9	Lift RRFLR to respot station	4.90
G2	Spot weld	275.00
G3	Lift RRFLR to Floor Complete station	2.60
F11	Back to station	8.20
	Total	494.00

5.0 SIMULATION MODEL DEVELOPMENT

The QUEST software was used to simulate the existing welding line. QUEST is a complete 3D digital factory environment for process flow simulation analysis, accuracy, and profitability. The discreet event simulation environment in QUEST is flexible, object-based, and features powerful visualisation and robust import/export capabilities that enables user to develop and prove out best manufacturing flow practices throughout the production design process. By using QUEST to experiment with parameters such as facility layout, resource allocation, kaizen practices, and alternate scheduling scenarios, the impact of each decision on production throughput and cost can be quantified.

The simulation methodology employed to build the basic model for the current system is discussed in the following sections.

5.1 Problem Definition

The simulation model built is aimed at capturing the current situation at the welding stations within the scope of study.

The objective of this simulation can be presented as the total profit obtained by multiplying total floor complete and revenue. It is as follows:

$$\text{Total profit} = N \times Rev \tag{1}$$

where, N = Number of FLOOR COMPLETE subassembly welded
Rev = Revenue gained per unit car sales

N is the performance measurement of the simulation model and the relationship of variable N with other factors can be represented by the equation:

$$N = f\,(N_{mc}, N_{op}, T_{cyc}, T_{idle}, FCFS, LB) \tag{2}$$

where, N_{mc} = Number of workstation; N_{op} = Number of operator
T_{cyc} = Operation cycle time; T_{idle} = Operator idle time
$FCFS$ = First come first serve; LB = Line balance
------ Underlined are controllable factors

The scope of study for this project involves only the first 8 welding stations that are responsible to produce the Floor Complete subassembly in the H-N welding line. These stations have a total of nine (9) operators to carry out welding operations. This study did not include breakdown of the welding guns.

5.2 Data Collection

Data collected prior to the construction of basic model includes studying the operation manual, observation on the operations carried out and their sequences, processing time of each work element determined using time study and the parts and welding guns involved. Generally, the work elements can be grouped into three main operations which simplify the modelling process. The processes carried out in each station, its distribution and the operators assigned are shown in Table 6.

Table 6 Detailed model description

No.	Station name	Machine name (Model)	Assigned operator	Operator name (Model)	Process type	Process time distribution (sec)
1	Dash key	DC	FF b	oFFb_1	SP =	N~(102.67, 5.05)
					CP1 =	N~(203.17, 5.15)
2	Front floor	FF	FF a	oFFa_1	SP =	N~(49.25, 2.36)
			FF b	oFFb_1	CP1 =	N~(33.33, 2.09)
					CP2 =	N~(184.75, 15.35)
					UP =	N~(36.33, 1.86)
3	Front floor respot	FFrspt	FF r	oFFr_1	CP =	N~(386.60, 19.20)
					UP =	N~(28.40, 4.67)
4	Centre floor	CF	CF	oCF_1	SP =	N~(35.80, 5.22)
					CP =	N~(335.2, 11.71)
					UP =	N~(19.4, 6.43)
5	Centre floor respot	CFrspt	CF r	oCFr_1	CP =	N~(503.20, 10.46)
					UP =	N~(14.80, 2.39)
6	Rear floor	RF	RF	oRF_1	SP =	N~(47.40, 4.56)
					CP1 =	N~(125.40, 6.43)
					CP2 =	N~(137.00, 5.15)
					UP =	N~(9.80, 1.48)
7	Rear floor respot	RFrspt	RF r	oRFr1	CP =	N~(550.00, 11.73)
					UP =	N~(2.60, 0.55)
8	Floor complete	FC	FC a	oFCa_1	SP =	N~(60.60, 2.53)
			FC b	oFCb_1	CP =	N~(396.5, 3.10)
					UP =	N~(61.70, 1.82)

* SP = Setup Process, CP = Cycle Process, UP = Unload Process
** All processes are assumed normally distributed, N~ (μ, σ)

5.3 QUEST Simulation Model

Based on the conceptual model and the details on type of processes, process time and its distribution, labour assignment, and process precedence relationship, the simulation model for the current system was built using the QUEST software. In general, six basic elements were used to build the basic model. They are machine, labour controller, labour, buffer, source and sink.

The simulation model is built upon these assumptions:

(i) Welding station is considered a machine and operator working at welding station is modelled as labour.

(ii) Parts produced is set to have a constant inter-arrival time of 500 seconds. They are sent to buffers to ensure continuous material supply such that these buffers can be considered as trolleys placed near work stations.

(iii) Cycle times for operations (Cycle Process, Setup Process Load and Unload Process) carried out at welding stations are assumed normally distributed and labour is required for every operations carried out.
(iv) Similar work elements are combined together to simplify the processes carried out by each machine, i.e. clamping parts and unclamping them is modelled as a Setup Process.
(v) Operate normally without breaking down throughout all the simulation runs.
(vi) Labour moving speed is assumed to be 0.61 m/sec.

5.4 Verification and Validation of Basic Model

Model verification is conducted by checking the element connections, which determine the flow of materials within the model. Then, the labour requirements at each machine are checked to ensure the labour assignment and labour movement is modelled correctly. The sequence of each process carried out in the model is ensured to follow the process flow in the current system to satisfy the precedence requirement.

For model validation, the number of Floor Complete subassembly produced daily and the percentage of line balancing loss (%LBL) calculated were used to validate the result from QUEST model. The percentage of LBL for the current system is 20.30% while the estimation of the number of Floor Complete subassemblies produced is shown as follows:

Available production time (min) per day $= 8 \text{ hr} \times 60 \text{ min}$
$= 11.34 \text{ min} = 480 \text{ min}$

Longest cycle time (Floor Complete Station) $= \dfrac{480 \text{ min}}{11.34 \text{ min}}$
$= 42.33$ units

Maximum number of Floor Complete per day = 42 units

From the results of the basic model after 8 hours running using the current system cycle time, the %LBL was 17.78%. Using an error limit of 5%, the %LBL for the simulated basic model when compared to the actual %LBL is considered acceptable as the calculated error is 2.52%. The maximum number of Floor Complete subassembly produced is 41 units. When compared to the calculated result for the existing system, the output by the simulation model is only one unit less than the output for the existing system which is 97.62% accurate. With that, the simulation model is validated as it is able to capture the real situation with high accuracy and this enables further modification on the model to represent the alternatives for improvement.

5.5 Experimentation

The experimentation stage addresses issues involving warm-up period, run length and number of replications required. Firstly, the determination of warm up period is important as the simulation result is collected after the system reaches the steady state. The number of Floor Complete subassembly produced was used to determine the warm up period. The warm up period for the basic model is identified to be two hours and is assumed to apply to the other alternative models.

As the basic model did not include breakdown events, all the processes modelled occurred every time a Floor Complete subassembly is produced. Hence, the run length for basic model is decided to be 8 hours for each run. Random number streams are used to generate the distribution specified in all the processes carried out in the simulation model, so it is improper to draw conclusion based on the results generated by a single model run. Due to this, the basic model is replicated for 10 runs, each with different set of random numbers assigned to collect result for the total FLOOR COMPLETE subassembly produced, operator idle time and the line balancing loss.

5.6 Alternative Models

(i) Basic Model: the basic model is aimed at capturing the current situation in the welding line studied. Result obtained from the model was used as a base for the modification in alternative models.

(ii) Alternative 1: the WIP storage size was increased. Additional storage space is added between Rear Floor and Rear Floor Respot station; and between Front Floor Respot and Floor Complete station. Buffers are used to represent the overhead hoist used in the welding line where the buffer size equals the number of carriers used.

(iii) Alternative 2A: the technique of combining or dividing work elements is used in the modification of task assignment for some operators. Work load for Floor Complete A and Floor Complete B is reduced by loading additional work elements to Rear Floor as mentioned in Section 4.0.

(iv) Alternative 2B: task assignment for Front Floor A and Front Floor B is modified by loading Front Floor Respot found to be idle often with tasks specified in Table 4. In this task arrangement, Front Floor B is released to finish tasks at Dash Complete station earlier while operation for Front Floor A is improved as the tasks carried out is simplified. On the other hand, the tasks performed by Rear Floor operator and Rear Floor Respot operator are combined together where they will jointly carry out all the work elements at Rear Floor and Rear Floor Respot station.

(v) Alternative 2C: this alternative is similar to Alternative 2B except that the task assignment for Rear Floor and Rear Floor Respot operators remain the same as in the basic model.

6.0 SIMULATION RESULTS AND DISCUSSION

The alternative simulation models are replicated for 10 runs in order to obtain results of the performance measures. The results obtained from the simulation model run are presented in Table 7. The performance measures considered are the total output, percentage of line balancing loss (%LBL), and operator idle time.

Table 7 Simulation result for performance measures selected

Category	Model name				
	Basic model	**Alt 1**	**Alt 2A**	**Alt 2B**	**Alt 2C**
Floor Complete produced (unit)	40.90	40.90	38.40	40.90	40.90
Total idle time (min)	24.78	25.12	29.43	18.41	18.32
%LBL	17.71	18.08	19.91	11.33	11.62

Total output obtained from the results indicate that there are no significant improvement to the number of Floor Complete subassembly produced by all the alternative, instead, Alt 2A recorded a decrease in the total unit produced. As for the operator idle time, Alt 1 and Alt 2A showed an increase in total idle time compared to the basic model while Alt 2C gave the lowest operator idle time. Alt 2B was found to have the lowest line balance loss percentage (%LBL) compared to the rest of the alternatives. As the alternative cannot be evaluated based on any of the performance measured individually, a thorough evaluation is required to compare each alternative before any conclusive proposal on the best alternative is made.

To conduct evaluation, a set of evaluation criterion need to be selected. The selection was based on the objective of the study, which is to improve the high operator idle time problem. Hence, the total idle time experienced by all the operators in the welding line was considered as one of the evaluation criteria. The total number of Floor Complete subassembly produced and the percent of Line Balance loss (%LBL) were also selected as the evaluation criteria to compare the productivity improvement and to quantify the line balance loss.

A scoring method was used to differentiate between alternatives that best satisfy an evaluation criterion and those that do not. For the desirable alternative, a score of 5 is given while an alternative found unsatisfactory is given a score of 1. As for those alternatives that have the same results as the basic model, a value of 3 is given. This evaluation results are shown in Table 8.

From the results, it was observed that Alt 2B and Alt 2C ties with a total score of 13. The tiebreaker factor decided here is the total operator idle time saved. From the previous analysis, Alt 2C is more effective in reducing the total idle time experienced by operator than Alt 2B. Alt 2C also did not involve complex labour movement as opposed to Alt 2B, in which the operator Rear Floor A is required to travel between

Table 8 Improvement alternatives evaluation result

Evaluation criteria	Alt 1	Alt 2A	Alt 2B	Alt 2C
Total output	3	1	3	3
Idle time	1	1	5	5
%LBL	1	1	5	5
Total	5	3	13	13

work station Rear Floor and Floor Complete. Therefore, Alt 2C is selected as the proposed solution.

7.0 CONCLUSIONS

This paper has presented the findings of a simulation study on productivity improvement using QUEST software for a car assembly factory. This study has identified the problems affecting the productivity of the welding line in the factory. The unbalanced line problem is dealt with using line balancing techniques to develop improvement alternatives. Simulation of the current condition in the selected welding line is conducted to explore options for constructing improvement alternatives based on the predefined performance measures which successfully demonstrated the use of QUEST software in this study. Based on the results of the performance measures selected, evaluation of the alternatives was conducted and recommendations were made. The use of simulation software has provided benefits in testing the developed alternatives, where it serves as a cost-effective way to determine the effect of the improvement alternatives on the performance measures without actual implementation and without disrupting the production activities. Future study can enhance the results obtained here by incorporating other variables such as breakdown in the welding process.

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