International Journal of Nanoelectronics and Materials
Volume 15 (Special Issue) March 2022 [313-321]

Simulation-based Assembly Line Balancing and Manpower Allocation in a Cellular Manufacturing System

R. Abdullah[1*], M. N. Abd Rahman[2], A. H. Abdul Rasib[1], M. I. H. C. Abdullah[1] and H. O. Mansoor[3]

[1]Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka
[2]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka
[3]College of Administration and Economics, University of Fallujah, Iraq

ABSTRACT

A well-balanced manufacturing system is key for ensuring a smooth production flow and the most efficient use of manpower and equipment This study aims to improve the cellular manufacturing system's assembly line balance and achieve optimal manpower utilisation at the bottleneck process. The methodology for evaluating the equipment and manpower performance for the manufacturing system was WITNESS simulation modelling and Maynard Operational Sequence Technique. Based on the simulation results, the test process was the bottleneck and the existing production was struggling to meet the customer demand due to machine shortages. Overproduction waste and a high work in progress inventory were discovered due to an imbalance in the Die Clip Bond and Trim and Mark processes causing overproduction wastes and very high work in progress inventory. A more balanced production line was observed after changes to the Die Clip Bond, Test and Mark and Test machine configurations. Inventory wastes at the Die Clip Bond and Trim and Mark were reduced by 52% and 73%, respectively. The test area's manpower was kept at two, but two machines were added to increase the machine capacity and meet expected increases in customer demand. The top three major contributors to the high manpower utilisation of 98% during stagger break were identified and proposed to be the focus for productivity improvement projects. Overall, simulation and MOST work study technique have proven to be effective tools for evaluating the performance of cellular manufacturing system.

Keywords: Simulation modelling, Maynard Operational Sequence Technique (MOST), work study, manpower allocation

1. INTRODUCTION

The Covid-19 pandemic, as well as fluctuating global demand and fierce competition among product suppliers, have posed challenges to the manufacturing industry. To deal with product complexity and respond to various customer demands, one strategy used to manage the manufacturing system is to use cellular manufacturing (CM) technology [1]. CM is a lean manufacturing tool that helps to improve assembly line balance and reduce wastes like work-in-progress (WIP), defects, and movements, resulting in increased productivity and manufacturing flexibility [2]. Products with similar characteristics and process requirements can be grouped together in one family or cell using CM. As a result, CM has emerged as the most efficient method for reducing lead time, inventory, and operational costs.

However, both equipment and human resource issues must be addressed in order to achieve an effective line balance in a CM [3]. Bautista *et al*. [4] explained the general method of line balancing is to divide the work into groups of tasks, each of which is assigned to a specific workstation along the line. Workstations are locations where certain tasks (operations) on products are completed. Products are kept at each workstation for a specific cycle time, which corresponded to the time

*rohana_abdullah@utem.edu.my

between successfully completed units. To perform the operations, the workstation can be manned by a single operator or a small group of operators.

In general, line balancing is done in the traditional manner using heuristic and various algorithm models. Simulation modelling is beginning to be a popular tool to study line balancing in the semiconductor industry. Simulation is a way to build up models to represent real-world scenarios, identifying bottlenecks and enhancing system performance. It is a big benefit to improve the performances by using a valid simulation model. The more realistic a simulation representation is, the more essential and effective it is for the design, test and experimentation of large scale engineering system that are becoming increasingly complex with time.

The study aims to use the WITNESS discrete event system simulation and the Maynard Operational Sequence Technique (MOST) to help solve the problem of manufacturing assembly line imbalance. First, the product, process flow, cycle time, setup time, overall equipment efficiency, lot sizes, manpower allocation or man-to-machine (M2M) ratio per machine, idle time and available working hour information were gathered. Next, MOST was used to map the operator work activities and time details, and the data was used as inputs for the simulation model. After that, a simulation model was developed, verified and validated. Throughput, bottleneck process, equipment utilisation and M2M ratio information could be analyzed using the validated simulation model.

2. ASSEMBLY LINE BALANCE AND SIMULATION

The line balancing problem is a classic problem that has been studied for more than 50 years. Line balancing is a technique used to manage the bottleneck and remove excess capacity by levelling the workload along the value stream [5]. Furthermore, according to Falkenauer [6], line balancing is a classic Operations Research (OR) optimisation problem that has been addressed by OR for several decades with algorithms and mathematical problems. The Assembly Line Balancing Problem (ALBP) and its variants also are studied using several mathematical modeling techniques, exact algorithms, and heuristic approaches. The mathematically modeling techniques include binary integer programming and goal programming techniques, while, exact algorithms include the branch-and-bound algorithm and dynamic programming approaches. Heuristic approaches include the generic algorithm, tabu search as well as ant optimisation approaches.

All of the methods had the same goal in mind, which was to find the best solution to the problem. However, heuristics approach is the most common technique used for assembly line balancing (ALB) problem. In general, heuristic approach refers to experience-based or known as intuitive problem-solving technique, the most fundamental of which is trial and error. Heuristic approach provides good and sometimes optimal sets of solutions to the line balancing problem. Examples of ALB using heuristic approach include studies by Ho and Emrouznejad [7], Zhang *et al*. [8] and Rajakumar and Selladurai [9].

The simulation technique is another method that has increasingly becoming popular for performing line balancing. Banks *et al*. [10] described simulation as the imitation of the operation of the real-world systems, processes, or systems over time. Whether done by hand or on a computer, simulation involves the construction of an artificial history of a system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system. Simulation is an easy way to build up models to represent real life scenarios, identify bottlenecks, and to enhance the system performance. By using a validate simulation model, it will have vast advantages in creating better manufacturing design in order to improve system performances.

Over the years, simulation-based line balancing has been practiced in a variety of industries. In addition, line balancing using simulation techniques can be done in a particular industry to identify the unbalanced line, run experimentation runs to observe the improvement and eventually, propose implementation. Simulation is a very good technique because it prevents the actual production runs from being affected until the simulation model's confirmation results are proposed and implemented. Yilmazlar *et al*. [11] conducted line balancing case study using simulation, which resulted in improved cycle time and throughput in a major household appliance industry. Yemane *et al*. [12] used a similar approach in the garment industry which resulted in 42% increase in line efficiency and a 10% increase in system utilisation.

3. MAYNARD OPERATIONAL SEQUENCE TECHNIQUE (MOST)

Both equipment and human activity times must be gathered in order to prepare the data input for the simulation model. Work measurement is used to identify the various production process elements, determine the time each element takes, and set the standard time to perform the production process. Time study is the work measurement technique used to gather time to perform a job. The stop watch is the most common time study method to study the process or equipment time, though historical data and work sampling can also be used [13]. Work measurement is an application technique to determine a qualified employee's time to perform certain jobs at a certain performance level. The predetermined time standards (PMTS) method is most suitable to be used. When measuring the employee's work.

Four techniques in the PMTS category are method time measurement (MTM), modular time standard modulation, factor of work and Maynard operational sequence technique (MOST) [14]. MOST is an easy to implement and maintain work measuring system [15]. It is a system for measuring work and focuses on object movement. Object motion follows certain patterns that are consistently repeated, such as reach, grasp, move and position of the object. These sequences can be identified as a series of events that manifest the movement of an object. A sequence model is developed and served as a guide for analyzing the motion of an object. MOST was designed to be significantly faster than other measurement methods. The precision principles that apply to MOST are the same as those used in statistical tolerance control. This means that the precision with which a component is manufactured is determined by its role in the final assembly. Similarly, with MOST, time values are calculated based on the final time level's overall accuracy. It is also sensitive to the time differences that various methods require. MOST is also very good at evaluating alternative performance methods in terms of time and cost [16].

4. SIMULATION MODELLING AND ANALYSIS

4.1 Current Production Line Simulation Model

The current production line simulation model is developed using a well-established simulation modelling systematic approach. The simulation approach consists of seven-steps, as follows:

Step 1: Defining the Objective and boundary conditions
Step 2: Data Gathering
Step 3: Model Building
Step 4: Model Verification
Step 5: Model Validation
Step 6: Model Analysis and Experimentation
Step 7: Project Deliverables and Documentation

In step 1, the objectives were set to focus on ALB and optimising the M2M of a semiconductor component manufacturer's selected cellular manufacturing system. The models were developed to allow to make it simple to manipulate the input and observe the output, as well as to make it easy to modify them. The process flow involved were defined as die clip bond, mould, trim and form and test. The model objectives, which guide in the information and data gathering, are based on the development of both the equipment capacity and the M2M ratio model. The following points were adopted to the model and used throughout the study:

(a) Parts will flow according to lot size, with the average units in each lot size being used.
(b) The machine cycle time would be multiplied by the desired overall equipment efficiency (OEE) value set by the company.
(c) Non-value added and necessary non-value added tasks are modelled as non-productive task in the simulation model to determine the labour utilisation.
(d) Throughput and the labour utilisation were the parameters that would be displayed for future experiment run.

Model assumptions were set in the initial design of the model to define the boundary of the experiment and the model's development path. The following assumptions were made for the study:

(a) The production line never starved (continuous flow).
(b) Production continuously run for 8 hours per shift and 24 hours per day.
(c) Machine setup and breakdown were modelled as the overall equipment efficiency (OEE) for the equipment capacity model.
(d) Non-value added tasks and necessary non-value-added tasks were modelled as non-productive tasks in the man to machine ratio model.

In step 2, data regarding the machine cycle time, overall equipment efficiency were gathered. The cycle time of the equipment was calculated by converting the units per hour (UPH) produced by the equipment. This model is based on a surface mount technology product called SMA, with target output of 225K units per shift. A MOST study was conducted on the Manufacturing Specialist (MS) activities in order to gather detail information regarding the time required to complete each activity.

Step 3 involved using the Witness simulation software to develop an equipment capacity base simulation model using the information gathered. The equipment capacity base model is shown in Figure 1.

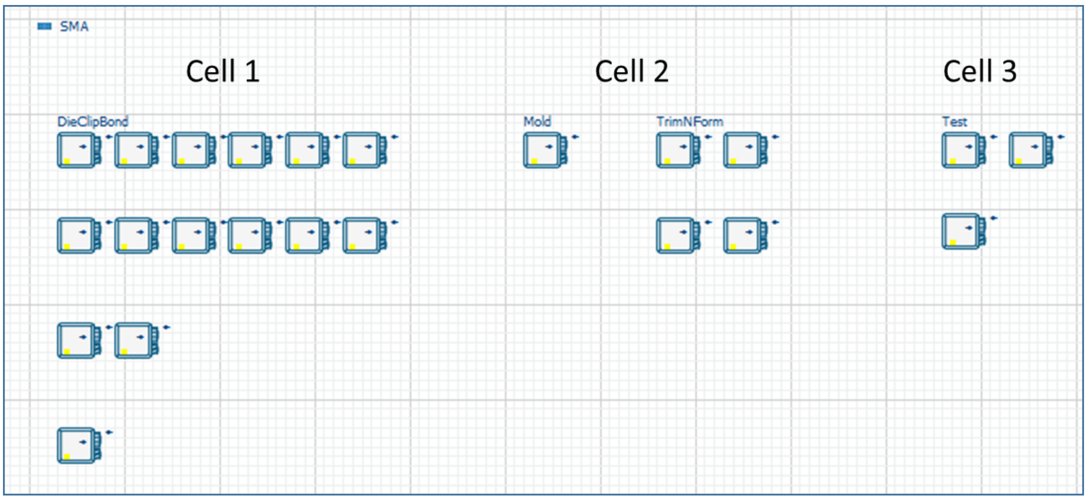


Figure 1. Equipment capacity base simulation model.

In step 4, the base simulation model was verified by ensuring the model was built correctly with the correct number of equipment used and that the product followed the right process flow. In step 5, the simulation model was validated by comparing the simulation model throughput to the real world system. Prior to gathering the statistics, the equipment capacity model was run for 480 minutes (1 shift) with two-shifts warm-up period. The difference between actual production throughput and simulation results was within the acceptable level of 10% in all the processes.

4.2 ALB Improvement

In step 6, the validated model was ready to be used for experimentation in order to explore ways to improve the ALB and MS utilisation. The line balanced of the base simulation model was first analysed. Figure 2 shows the line balance chart for the throughput per shift, indicating that the test process was the bottleneck, with a capacity of 189K per shift, which was less the demand per shift of 224K.

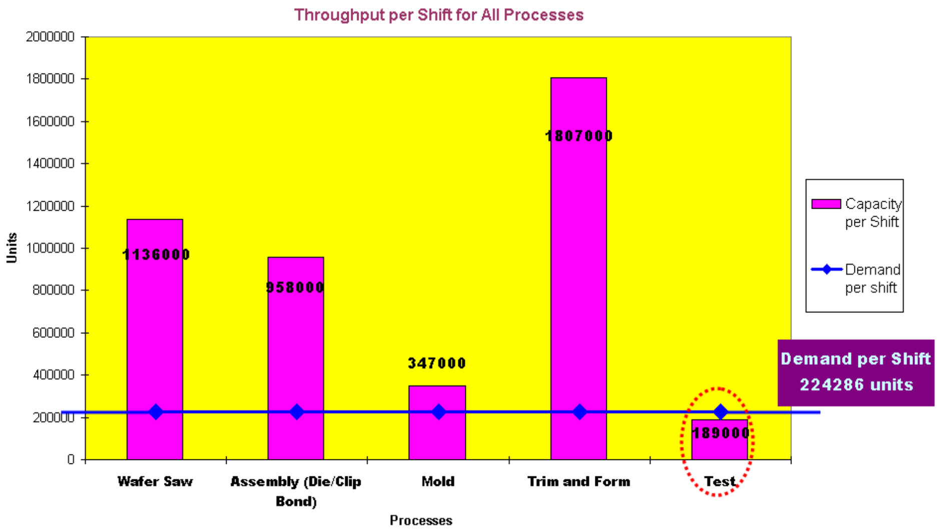


Figure 2. Existing manufacturing assembly line balance.

In the existing production line, there were only 3 test equipment assigned to process the customer demand at the test area. Due to an increased in customer demand, the company's management would like to target for a 300K per shift capacity. As a result, two more test machines should be added. However, with the Trim and Form capacity to be at 1.8KK causing unnecessarily high inventory wastes, the quantity should be reduced from 4 to only 1 machine. In addition, the 15 Die Clip Bonds should also be reduced to only 7. Table 1 shows the difference in equipment quantity between the existing and a more balanced manufacturing line. For both models, the overall equipment efficiency (OEE) was kept at 85%.

Table 1 Difference in Equipment Quantity

Process	Existing Equipment Quantity	New Equipment Quantity	OEE (%)
Die Clip Bond	15 machines	7 machines	85
Mold	1 machine	1 machine	85
Trim and Form	4 machine	1 machine	85
Test	3 machines	5 machines	85

Figure 3 shows the result of the more balanced manufacturing line meeting the current customer's 224K per shift target as well as the forecasted new customer demand of 300K per shift. Because customer demands for other products in the same surface mount technology was expected to rise, the extra 8 Die Clip Bond and 3 Trim and Form machines were planned to be converted to process these products. With the reduction in the number of equipment, the production was able to reduce overproduction waste at Die Clip Bond by 52% and at the Trim and Form by 73%.

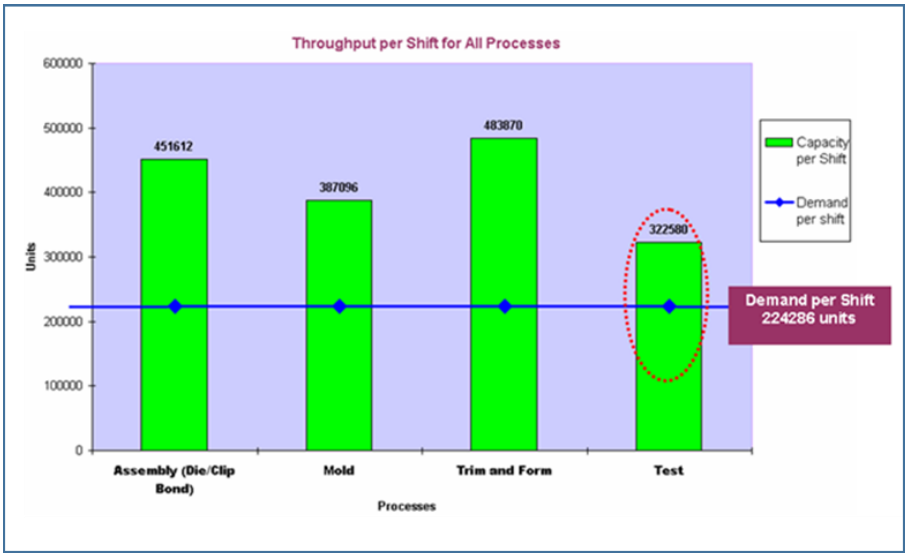
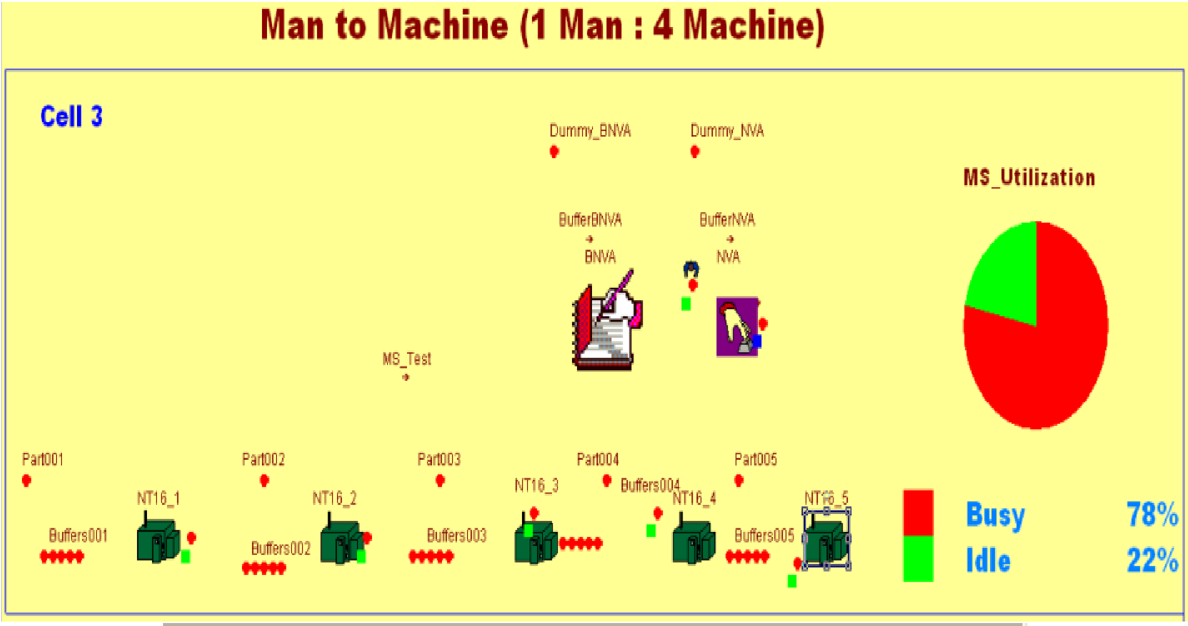


Figure 3. Improved manufacturing assembly line balanced.

4.3 Operator Utilization and Man to Machine Ratio Improvement

Using the input data from the MOST analysis, an M2M ratio simulation model for the Cell 3; test process was also developed. The simulation was executed and the percentage of MS utilisation was recorded for one shift (480 minutes). When compared to the calculated value obtained from the MOST study, the percentage of utilisation for a MS handling an equipment was observed for the test process and was found to have a similar result. The model was designed to evaluate current MS utilisation in a 1 man to 1 machine ratio model of the test area over the course of 1 shift (480 minutes). The result showed that if the MS only handled one machine, the test MS was only utilised 20% of the time. the allowance for a female MS working in a standing position are set at is 15% by the International Labour Organization (ILO), thus, the target for the MS utilization was set at 85%. A series of simulation models were run to observe the 1 MS manning 1,2,3,4 and 5 test machines until the 85% utilisation target was achieved. The result showed that the best case scenario was 1 MS manning 4 test machines at 78.22% utilization. Figure 4 presents the results of the man to machine simulation model.

There need to be a minimum of 2 MSs manning the cell due to the stagger break requirement for the cell. Currently, there are 2 MSs assigned to this cell. Based on the simulation result, the utilisation of these operators were between 60% (1 man to 2 machines) and 80% (1 man to 3 machines). However, during the stagger breaks where only 1 operator was available at the test cell, the utilization of this MS was at 98%. Figure 5 presents the analysis of the manning activities showing three main activities consuming the MS's time; (i) Start new lot (27.6%), Machine Assist (21%) and Reel Change (35%). Consequently, these 3 activities were proposed to the manufacturing management teams as the focus for improvement projects aimed at reducing the MS's utilisation, particularly during stagger breaks. Further, cross-training option was also considered for the Test MS to also support the Trim and Form cell during the shift.



Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Job
MS_Te	78.22	21.78	1	112	111	

Figure 4. Man to machine simulation model.

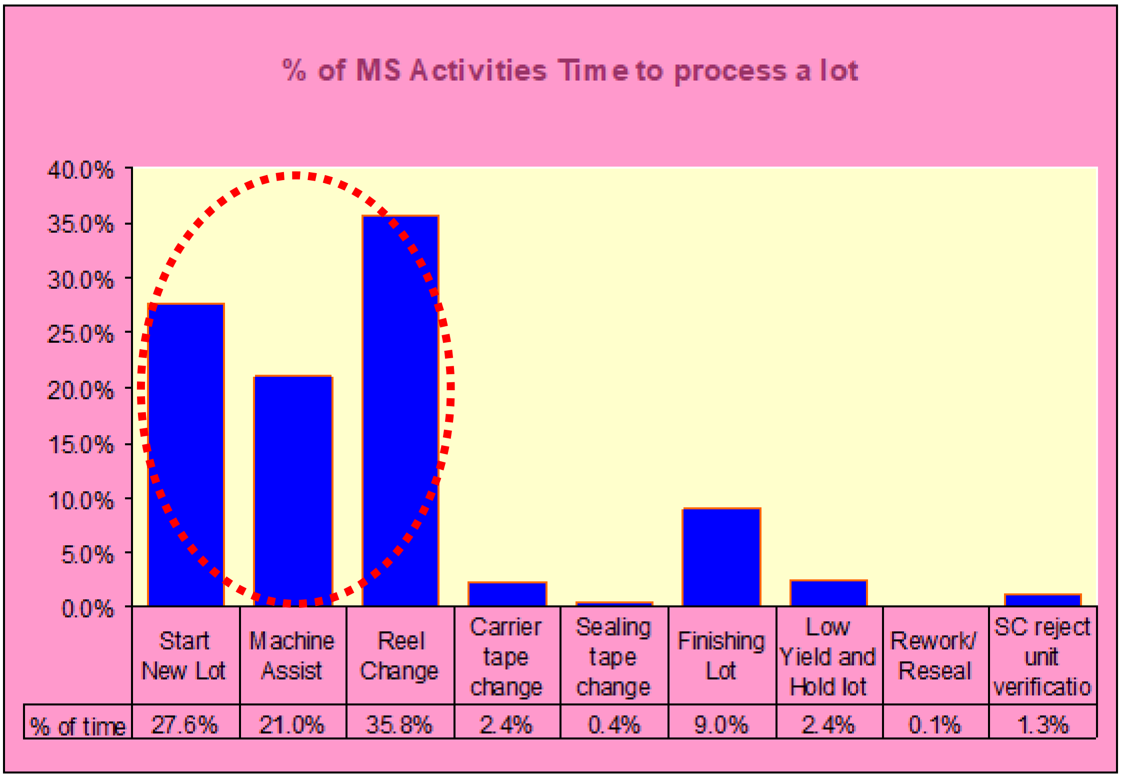


Figure 5. Analysis of the Manufacturing Specialist (MS) activity time.

Step 7 of the simulation study involved documenting the work in a proper report and manufacturing presentation after the detailed evaluation of the various conditions to improve the ALB, operator utilisation, and man to machine ratio at the SMA manufacturing cell was completed. The cost avoidance realised by not having incur any cost for additional Die Clip Bonds and Trim and Form equipment for other products' capacity expansions helped the company to justify for the purchase of the extra 2 testers.

5. CONCLUSION

The Assembly Line Balance (ALB), operator utilisation, and man to machine ratio were investigated in this study. WITNESS simulation software and also MOST data inputs were used to evaluate two equipment capacity models and five man to machine ratio models. The test process at Cell 3 was found to be the bottleneck, constraining capacity and causing the production line to struggle to meet the customer demand. On the contrary, this cell had an excessive number of Die Clip Bond and Trim and Form machines, resulting in overproduction waste and high unwanted inventories. By adding 2 testers but reducing the quantity of 15 Die Clip Bond machines to only 7 machines and from 4 Trim and Form machines to only 1 machine enabled the production line to meet the current customer demand as well as their new target. This also resulted in millions of ringgit in cost avoidance for not having to purchase new machines for other products' capacity expansion plan.

Further, the MS utilisation was also evaluated using the 5 test machine models, and the results showed that the utilisation of the 2 MSs were between 60% and 80%, with the utilisation reaching it's peak at 98% during stagger breaks where only 1 MS was left to man the entire test cell. The work contents of the MS were analysed, and three major activities contributing to the high utilisation were identified as areas for improvement. It is found that simulation modelling is a powerful tool to be used for ALB evaluation in a cellular manufacturing process to reduce wastes and improve labour productivity. For further study, more experimentations should be done to optimize other work cell's manpower utilization and man to machine ratio. The top three contributors to the high operator utilization also required a detailed study using suitable technique such as Lean Six Sigma.

ACKNOWLEDGEMENT

The authors would like to extend a special thanks to the PJP/2020/FTKMP/PP/S01778 grant, the Centre of Research and Innovation Management (CRIM), the Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka and the participating manufacturing company for providing the facility and data that enabled the completion of this study.

REFERENCES

[1] G., Egilmez, B. Erenay, G. A. Süer, Journal of Manufacturing Systems. Stochastic Skill-Based Manpower Allocation in A Cellular Manufacturing System. vol **33**, issue 4 (2014) pp. 578-588.

[2] P. Singh, B. Saini, M. Vishwakarma, International Journal of Engineering. Management and Medical Research. Application of Lean Manufacturing Tools in Garments Production. vol **4**, issue 10 (2018) pp 1-58.

[3] B. Bidanda, P. Ariyawongrat, K. L. Needy, B. A. Norman, B. A., Tharmmaphornphilas, W. Computers & Industrial Engineering. Human Related Issues in Manufacturing Cell Design, Implementation, And Operation: A Review and Survey. vol **48**, issue 3 (2005) pp 507-523.

[4] J. Bautista, J. Pereira, European Journal of Operational Research. A Dynamic Programming Based Heuristic for The Assembly Line Balancing Problem. vol **194**, issue 3 (2009) pp. 787-794.

[5] J. Amardeep., J. Gautham, International Journal of Innovative Research in Science Engineering and Technology. Line Balancing of a single model Assembly Line. (2013) pp 23-29.

[6] E. Falkenauer, "Line Balancing in the Real World." International Conference on Product Lifestyle Management, (2000).

[7] W. Ho, A. Emrouznejad, Assembly Automation. A Mathematical Model for Assembly Line Balancing Model to Consider Disordering Sequence of Workstations. vol **29**, issue 1 (2009) pp. 49-51.

[8] W. Zhang, M. Gen, L. Lin, International Conference on Systems, Man and Cybernetics. A Multiobjective Genetic Algorithm for Assembly Line Balancing Problem with Worker Allocation. (2008) pp. 3026-3033.

[9] S. Rajakumar, A. V. Selladurai, Journal of Manufacturing Technology Management. Workflow Balancing in Parallel Machine Scheduling with Precedence Constraints using Genetic Algorithm. vol. **17**, issue 2 (2006) pp. 239-254.

[10] J. Banks, J.S. Carson II, B.L. Nelson, D.M. Nicol, "Discrete-Event System Simulation" 5th Ed. New Jersey: Pearson Education Inc. (2010).

[11] O. Yilmazlar, A. Jeyes, A. Fiore, A. Patel, C. Spence, C. Wentzky, N. Zero, M. E. Kurz, J. D. Summers, K. M. Taafe. Procedia Manufacturing. A Case Study in Line Balancing and Simulation., vol **48** (2020) pp. 71-81.

[12] A. Yemane, G. Gebremichael, T. Meraha, M. Hailemichael, Journal of Optimization in Industrial Engineering. vol **13**, issue 1 (2020) pp. 153-165.

[13] R. Abdullah, N. Omar, S.R. Kamat, "Work Study for Overall Process Efficiency at Manufacturing Company". International Conference on Engineering Education, (2013) pp. 1-83.

[14] Y. Harari, R. Riemer, Bechar. Applied Ergonomics. A. Factors Determining Workers' Pace While Conducting Continuous Sequential Lifting, Carrying, And Lowering Tasks. (2018) pp.72-76.

[15] A. A. Karad, N. K. Waychale, N. G. Tidke, International Journal of Engineering and General Science. Productivity Improvement by Maynard Operation Sequence Technique. (2016) pp. 98-99.

[16] R. Abdullah, A. B. Mohd Rodzi, Journal of Engineering and Technology. Labor Utilization and Man to Machine Ratio Study at a Semiconductor Facility (2011) pp 20-22.