AN INNOVATIVE APPROACH OF MATERIAL FLOW SYSTEM FOR MOTION REDUCTION IN A CAST MANUFACTURING FIRM

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ABSTRACT: A door hardware manufacturing company in Melaka, Malaysia has faced challenges with an inefficient material handling system due to unnecessary operator movements in the sub-assembly processing line. This study aims to address this issue by proposing an innovative material flow system focused on three main stations: Manual Piston Assembly (MPA), Cushion Back Check (CBC), and Spring Adjustment Screw (SAS). The new material flow system is developed using Spaghetti Diagram (SD) and Line Balancing (LB), leading to improved operator movement and the reorganization of workstations and storage areas. Consequently, the distance between the storage area and CBC/MPA has been reduced by 88%, from 36.2 meters to 4.4 meters, and from SAS, it has been reduced by 72%, from 18.7 meters to 5.30 meters. This significant reduction has minimized worker motion and eliminated unnecessary movements. Overall, this study demonstrates that LB is an effective method for addressing bottlenecks and optimizing the material flow system in this cast manufacturing firm.

KEYWORDS: *Yamazumi chart; spaghetti diagram; line balancing; material flow system; Malaysian manufacturing company*

1.0 INTRODUCTION

Malaysia's manufacturing sector plays an important part in driving the nation's economic progress. In 2022, this sector contributed significantly to the nation's Gross Domestic Product (GDP), accounting for 23.4% of it, and amounted to RM59.4 billion, which represented 60.4% of the Total Approved Investments (TAI) in the first quarter of the year [1] and [2]. Consequently, the focus of this study has been directed towards a casting manufacturing firm situated in Cheng, Melaka, Malaysia with the objective of enhancing this industry at the local level. This specific production firm specialises in the production of door hardware, encompassing fittings, locks, electrified doors, emergency exits, and panic hardware.

In this ever-evolving environment and fiercely competitive manufacturing sector, optimising layout becomes an essential imperative to ensure the firm's reliability. According to research conducted by N.A.A. Norazlan et al [3], the crucial concern revolves around the adaptability of the layout to anticipate potential shifts in product demand. Tama et al. [4] and Ding et al. [5] emphasized the critical importance of selecting the appropriate facility strategy for businesses today to minimise any possible wastage and bolster flexibility, as corroborated by Komariah and Jhoansyah et al. [6] and Debnath et al. [7] Ghaffar et al. [8] highlighted that crafting a well-structured pathway for each movement within the production line will lead to a practical material flow scheme. This, in turn, will contribute to an increase in the firm's production efficiency, waste minimisation, cost reduction, and, ultimately, the enhancement of the firm's profit margins. Conversely, Yuniawan et al. [9] and Rafiei et al. [10] argue that achieving a balanced assembly line ensures the elimination of bottlenecks, resulting in heightened productivity and lower cycle times. The primary objective of line balancing lies in aligning the output rate with the manufacturing schedule, a crucial consideration throughout the design phases of a flow line manufacturing system. Consequently, as stated by Guo [11], assembly line balancing is utilised to ascertain the optimal distribution of workstation tasks, with the aim of minimising cycle times by evenly distributing the workload across workstations for a given cycle time.

This study addresses inefficiencies in a door hardware manufacturing firm's material flow system, specifically focusing on the Manual Piston Assembly (MPA), Cushion Back Check (CBC), and Spring Adjustment Screw (SAS) sub-assembly lines. The current material flow system, as shown in Figure 1, is disorganized, resulting in increased delay times at each station. This disorganization forces operators to spend more time navigating through the process, leading to inefficiencies and bottlenecks.

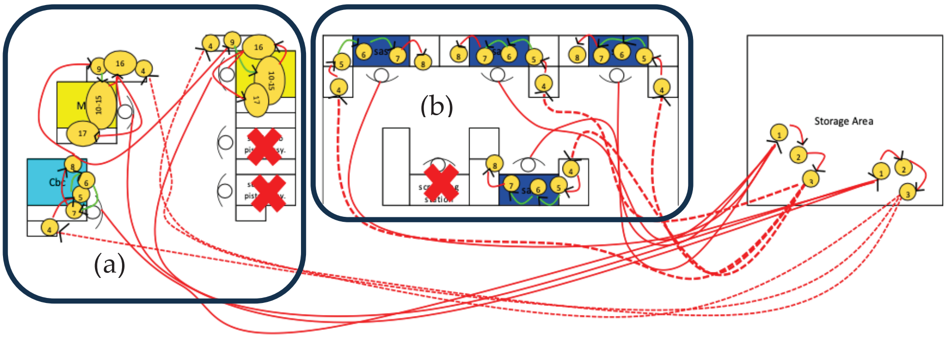


Figure 1: Spaghetti Diagram for existing (a) MPA, CBC, and (b) SAS workstation

The study's scope is limited to these three sub-assembly lines, excluding the examination of operational practices at each station. Instead, the study concentrates on proposing improvements to the material flow system for these lines. Table 1 provides indicators for each workstation's spaghetti diagram, highlighting the current inefficiencies in the material flow system. These indicators help identify areas where improvements can be made to reduce delays and enhance overall efficiency.

Table 1: The Signs and Indicators for all Spaghetti Diagram

Sign	Indicator
	Sprint adjustment screw station
	Manual piston assembly station (MPA)
	Cushion Back Check
	Not covered area research study
	Operators non-value
	Operators non-value-added activities from storage area to workstation
	Value-added activities material flow
	Task
	Operator

The review likely identified a lack of specific studies addressing the inefficiencies in material handling systems in door hardware manufacturing, especially focusing on operator movements and sub-assembly processing lines. Existing literature may have focused more broadly on manufacturing efficiency or lean principles without specific solutions for the door hardware industry. Hence the research objective of this study is to propose an innovative material flow system to address the inefficiencies caused by unnecessary operator movements in the sub-assembly processing line.

This objective indicates that the study aims to develop a practical solution tailored to the specific challenges faced by the door hardware manufacturing industry, which may not have been adequately addressed in existing literature or practices. Therefore, the novelty of the study lies in its specific focus on the door hardware manufacturing industry, proposing a tailored solution to improve material handling efficiency in sub-assembly processing lines, which may not have been previously addressed in the literature or industry practices.

2.0 METHODOLOGY

This study focuses on enhancing the facility layout to reduce material handling time in the production line of a cast manufacturing company. The methodology used is depicted in Figure 2, emphasizes the innovative use of a simple Spaghetti Diagram and Line Balancing, along with the Yamazumi Chart for quantitative optimization.

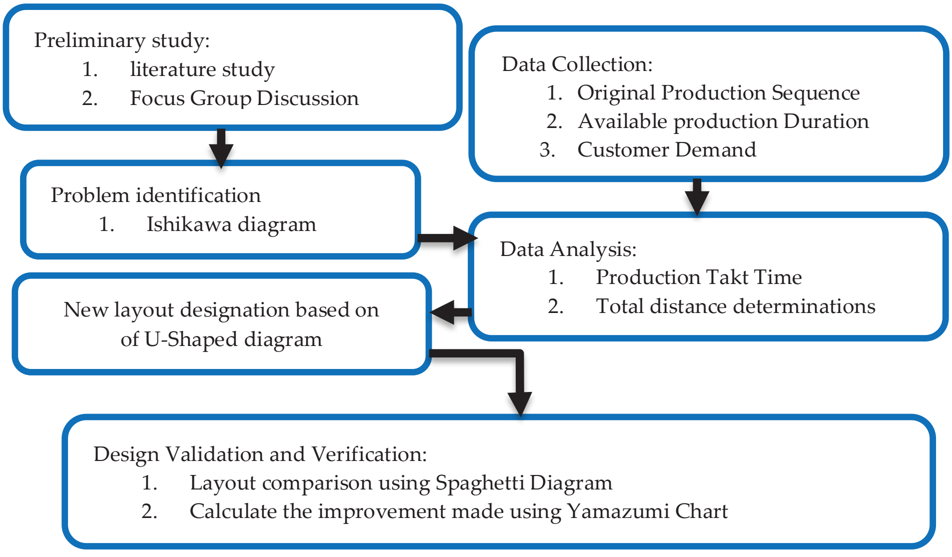


Figure 2: Research methodology

The study begins with evaluating the current material flow in all three sub-assembly lines to understand the real problem. This involves five operations: visually inspecting the existing material flow system, conducting semi-structured interviews through a Focus Group Discussion (FGD) with engineers and operators, and engaging in brainstorming sessions. Once the problems are identified, data is collected directly from the company by measuring and surveying all employees. The data is then processed according to the requirements for improving the sub-assembly layout. Next, a new material flow concept for the sub-assembly line is developed, incorporating the identified root causes. The Spaghetti Diagram and Yamazumi Chart are used to analyze this concept and ensure its effectiveness in minimizing material handling time.

3.0 RESULT AND DISCUSSION

3.1 Preliminary Data Collection and Analysis

The present layout of the facility is the initial input required for the new layout designation. As shown in Table 2 and 3 below, the activity of for both sub-assembly as well as the distance required is being listed and referred to for every purpose of Spaghetti Diagrams.

Table 2: Task Activity for CBC-MPA Station

No	Task	Distance (m)
1	Walking from the workstation to material storage	36.2
2	Searching for material	0
3	Walking back from the material storage to workstation	0
4	Uploading material	36.2
5	Dispense the steel ball and ball punching takes place	0
6	Riveting to seal the ball	0
7	Blowing process	0
8	Leak testing and auto segregation	0
9	Pick and arrange piston	0
10	Pick and arrange piston hole	0
11	Knock piston slightly	0
12	Arrange the inner side of piston using bare hands	0
13	Pick & arrange piston hole	0
14	Knock piston slightly again	0
15	Press the inner side of piston using bare hands	0
16	Air-blow and clean the area	0
17	Arrange piston inside nylon box	0

Table 3: Task Activity for SAS Station

No	Task	Distance (m)
1	Walking from the workstation to material storage	18.7
2	Searching for material	0
3	Walking back from the material storage to workstation	18.7
4	Uploading material at the workstation	0
5	Pick the adjustment screw with pressure disc and load it on the fixture	0
6	Check for the o-ring and attached to the adjustment screw	0
7	The cylinder travel down and turn SAS with the pressure	0
8	Unlock the gripper and unload the SAS	0

As depicted in Figure 3, the disorderly and tangled material flow resulted in prolonged material handling times. This was primarily due to the disorganized task sequence, which necessitated operators to make unnecessary movements. For instance, operators had to traverse from task 6 to task 7, located on opposite sides, and then move on to task 8, also situated on the opposite side. Additionally, after completing all tasks, operators at the CBC workstation had to transport all finished items to the storage zone.

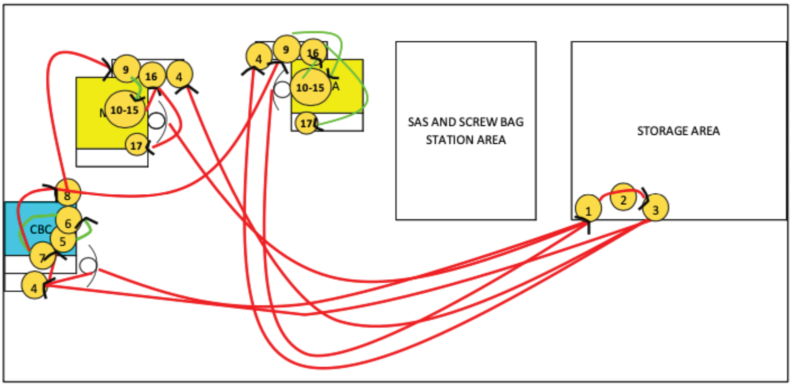


Figure 3: Spaghetti Diagram of the original layout CBC-MPA workstation

The inefficiency of this workflow was further exacerbated by the significant distances between workstations and the storage zone. The CBC-MPA workstation was 36.4 meters away from the storage zone, while the SAS station was 18.7 meters away. This considerable distance, combined with the disorderly task sequence, increased the time spent by operators in material handling tasks. Moreover, the inadequately organized racking system contributed to the delay in material handling times. Operators faced challenges in locating materials, which resulted in prolonged search times. This inefficient workflow required operators to shuttle between workstations and the storage area, leading to unnecessary motion and further delays in material handling.

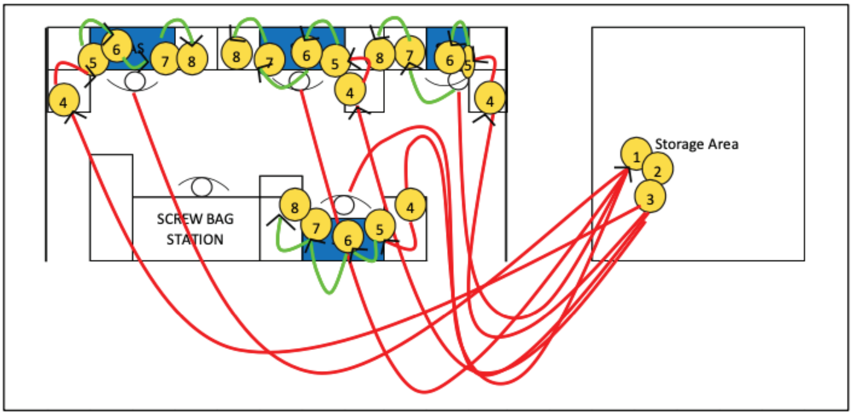


Figure 4: Spaghetti Diagram of the original layout SAS workstation

As seen in Figure 4, the three sub-sub operations were operating out of the SAS workstation. The storage zone was situated on the far right, creating a significant distance between the sub-substation's left side and the storage zone. Operators had to transport all the items manufactured in the SAS station to the storage area, which were widely separated. The time spent walking around disturbed the manufacturing cycle, leading to needless movement for the operators.

In this case study, a single batch shipment of completed items required 8.5 hours to finish. The takt time of the proposed material flow system was calculated to establish the rhythm of production [12] [13]. This measure signifies the allocated time for producing each part [14], and Table 4 displays the takt time computed for this study.

$$\text{Takt time} = \frac{\text{Customer Demand}}{\text{Available Production Time}} \tag{1}$$

Available production duration = 8.5 hours = 510 minutes

Table 4: The Takt Time of the Workstations

Workstation	Customer Demand (pieces)	Takt Time (s)
CBC and MPA	3929	7.79
SAS	1832	16.78

Furthermore, through the utilization of the Ishikawa diagram as shown in Figure 5, it was identified that the root causes of the disordered material flow in the sub-assembly line stemmed from four key elements: Methods, Materials, Men, and Machines. The interaction of these elements resulted in a chaotic flow of materials within the sub-assembly line. Specifically, products were being assembled at the storage zone's sub-assembly line, which could potentially contain defective items. Operators were then required to segregate the defective and non-defective goods at the workstation, leading to delays in each process.

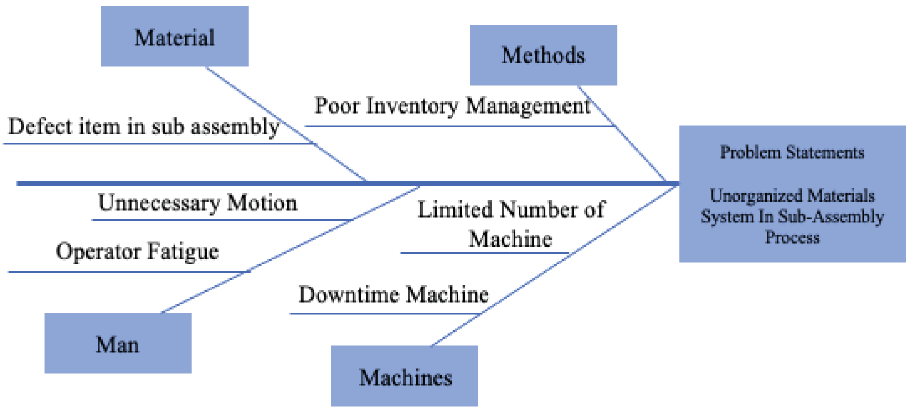


Figure 5: Ishikawa Diagram

Inadequate inventory management also contributed to the issue, as it necessitated excessive operator movement to access items from various stations. This excessive movement not only consumed valuable time but also limited the available time to complete operations, ultimately resulting in the failure to meet daily targets. Furthermore, factors such as allowances and staff fatigue were not considered, further impacting the sub-assembly's overall productivity.

3.2 The New Design of the Material Flow System for the Sub-Assembly Line

As shown in Figure 6, Spaghetti Diagram of the New Layout Design presents a redesigned layout for both the storage zone and the workstation, aiming to relocate the storage zone to decrease the distance between it and each workstation. Before this proposal, the distance between the storage zone and the CBC-MPA workstation was 36.2m, whereas the distance to the SAS workstation was 18.7m. The relocation of the storage space has decreased these distances to 4.41m and 5.30m, respectively. This concept enables operators to move more efficiently, resulting in reduced time for each task. The workflow of the station is also restructured into a U-line, enabling orderly task completion.

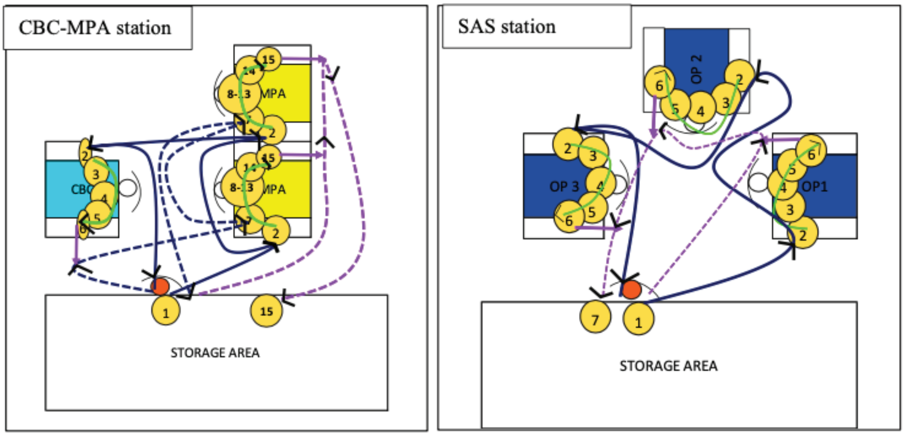


Figure 6: The Spaghetti Diagram of the New Layout Design for both CBC-MPA and SAS station

3.3 The Verification and Validation of the New Design

The Yamazumi chart has played a pivotal role in assessing the effectiveness of the new layout design by methodically balancing workloads and visualizing process enhancements. This tool has allowed for a quantitative analysis of workload distribution among various tasks, aiding in informed decision-making for layout optimization. Through the use of the Yamazumi chart, a comparison of workloads original and after implementing the new layout was conducted, revealing any areas of imbalance or inefficiency that required attention. Additionally, the chart has helped this research to identify areas for further improvement in the layout by visualizing workload distribution and suggesting adjustments to streamline processes and improve overall efficiency.

Takt time is a fundamental concept in the Yamazumi chart, serving as a standard for aligning production pace with customer demand. Calculated as available production time divided by customer demand, takt time sets the maximum time allowed per unit to meet demand. In the chart, takt time helps determine the work cycle for each task or process by dividing customer demand by the total work time (excluding breaks). This establishes a guideline for balancing workload across tasks. Tasks are represented by bars and comparing their lengths to takt time highlights tasks exceeding the allotted time, prompting adjustments to ensure overall production meets demand. Before employing the Yamazumi Chart for analysis, we categorised all activities as either Non-Value Added (NVA) or Value Added (VA) (Pre-implementation of the proposed material flow system)

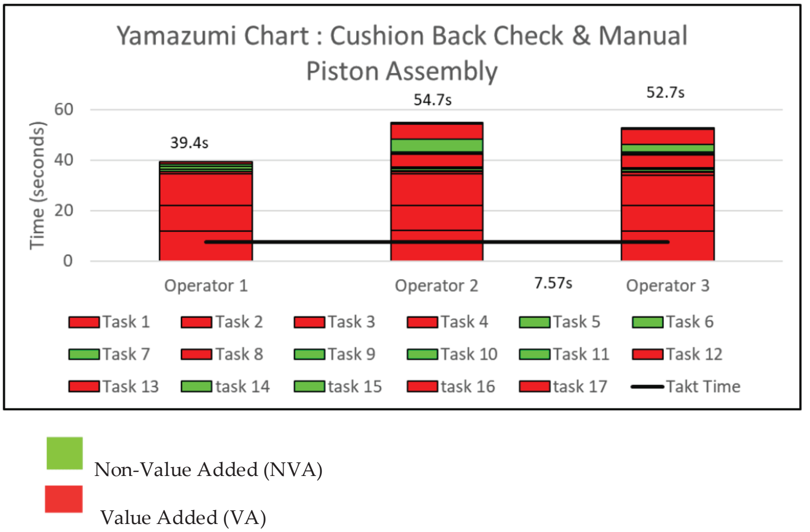
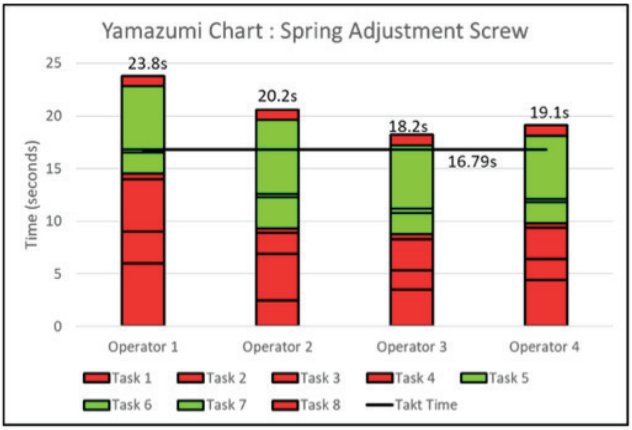


Figure 7: Yamazumi Chart of the CBC and MPA Workstations

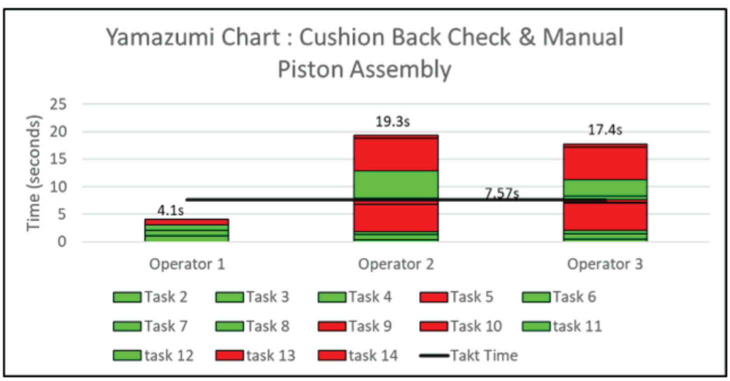
As seen in Figure 7, tasks 1, 2, 3, and 4 had no impact on the product, categorising them as NVA activities. Bottlenecks were identified among the three operators, with their average cycle times exceeding the takt time. Operator 3, in particular, had the lengthiest average cycle time because of aspects like fatigue and physical capabilities, even though it performed the same task as operator 2. With regards to the SAS workstation, as depicted in Figure 8, a significant bottleneck arose because fewer tasks were completed compared to the CBC-MPA station. Additionally, the takt time of this workstation was 16.79s longer than that of the CBC-MPA workstation, which was just 7.57s (Post-implementation of the proposed material flow system).



Non-Value Added (NVA)

Value Added (VA)

Figure 8: Yamazumi Chart of the SAS Workstation



Non-Value Added (NVA)

Value Added (VA)

Figure 9: The Yamazumi Chart of the CBC-MPA Workstation

As depicted in Figure 9, tasks 1, 2, 3, and 4 were eliminated from all the operators of the CBC-MPA workstation. Operator 1 had additional capacity since it carried out tasks that differed from that of operators 2 and 3. Notably, operators 2 and 3 remained bottlenecked as the NVA actions were crucial steps in task accomplishment. Tasks 1, 2, 3, and 4, identified as NVA activities, could be removed. The time study in the current scenario revealed that the overall cycle time for accomplishing these tasks at this workstation also decreased to 4.1s, 19.3s, and 17.4s for each operator.

4.0 CONCLUSION

In summary, by implementing the strategies outlined, this study successfully achieved both of its stated goals. The first objective involved scrutinising the existing material flow system in the sub-assembly line through observation and semi-interviews based on focus-group discussions. All observations were represented in the Ishikawa diagram, highlighting the major issue of a disorderly material flow system triggering inefficient operator movements.

The last and most significant objective of this research was to propose a new material flow system by utilising the line balancing method, analysed through takt time, and visualised with the Yamazumi and spaghetti diagrams. Consequently, the distances between workstations and the storage zone were reduced from 36.2m to 4.41m and from 17.8m to 5.30m. Additionally, non-value-added tasks were eliminated, addressing the bottleneck problem. In a nutshell, these strategies effectively removed bottlenecks and optimised material flow systems in the sub-assembly line.

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AUTHOR CONTRIBUTIONS

N.A.Q.M. Shafee: Original Draft Preparation, Data Collection, Data Analaysis; E. Mohamad: Conceptualization, Methodology, Supervision; M. S. A. Rahman: Methodology, Writing-Reviewing; A. A. Rahman: Writing-Reviewing and Editing; T. Ito: Validation, Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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