Optimizing Lean Manufacturing Efficiency with Novel Line Balancing in the Automotive Exhaust Manufacturing Sector

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Abstract - This study examined the application of Lean manufacturing tools and a novel approach called line balance loss analysis in optimizing production processes at a Malaysian automotive exhaust manufacturing company. The primary objective was to align production rates with customer demand. Data collection involved two key aspects: gathering production process data for catalytic converters, front pipes, and muffler subassemblies, and acquiring technical data on Lean tools, including the innovative line balance loss analysis method, from one muffler production line. The integration of Lean tools with the new line balance loss analysis approach was found to be crucial. The multi-process/multi-machine line balancing approach went beyond eliminating Non Value Added (NVA) activities and focused on determining manpower requirements and task allocation among operators. The integration of the new line balance loss analysis method improved task distribution across workstations, enhancing overall process efficiency. The study's analysis of Lean tool applications and the innovative line balance loss analysis provided insights into the cellular manufacturing system of the production line. These findings offered valuable information for management decision-making and process improvement, ultimately leading to increased productivity and cost savings for the company.

Keywords: Line Balance Loss Analysis, Non-Value Added, Cellular Manufacturing System.

1. INTRODUCTION

The modern automotive manufacturing industry has undergone significant advancements, driven by research, technology, and management science. Despite these strides, translating cutting-edge knowledge into successful industry applications remains a challenge, particularly in the face of intense market competition.

In the context of manufacturing management, the shift away from mass production toward smaller quantity, diverse orders has become a prevailing trend. Sticking to traditional manufacturing methods may hinder competitiveness, making improvements in production systems essential. Lean manufacturing stands out as a well-established approach that enhances production efficiency by eliminating waste. Originating from the Toyota Production System in the 1950s, Lean emphasizes the systematic removal of seven types of waste: overproduction, waiting time, transportation, over-processing, inventory, movement, and defective parts production.

Lean implementation is guided by a framework consisting of philosophy, foundational quality control aspects, and strategic tactics. In Malaysia, Lean tools like 5S, Value Stream Mapping (VSM), and work standardization have gained prominence in automotive assembly, although further adoption opportunities exist.

The success of Lean in reducing waste and improving efficiency is not limited to the automotive sector; it has also shown promise in biopharmaceutical manufacturing. Given the considerable production challenges in the automotive exhaust systems industry, Lean's application and its array of tools hold potential for optimizing production processes and increasing profitability.

This research explores the application of various Lean manufacturing tools in the automotive exhaust system production line. By examining the practical implementation of Lean in an experienced organization, this study contributes valuable insights to benchmark Lean tool effectiveness and identify relevant conditions for success. By summarizing the key points and removing redundant details, this introduction provides a concise overview of your research topic and its significance.

2. LEAN MANUFACTURING

Lean manufacturing has garnered substantial interest from both academics and industrial practitioners. This chapter provides a concise summary of fundamental theories and practices in lean manufacturing, with a focus on their relevance and recent advancements. Additionally, it explores related industrial cases and comparative studies of selected tools.

Lean manufacturing is a set of processes aimed at reducing and eliminating the seven key wastes: overproduction, waiting time, inventory, operator motion, transportation, defects, and excess processing. This approach is aptly named "Lean" because it achieves improved outcomes with fewer resources, space, inventory, investment, and employees while enhancing customer satisfaction (Wilson, 2010).

The central concept of lean manufacturing is the elimination of waste and non-value-added activity. "Value-added" activities enhance the product's form, fit, or function and are something customers are willing to pay for. Waste, on the other hand, refers to resources used in activities that do not generate value for the customer (M. Z. M. Ismail et al., 2019). Waste can be categorized into Type 1 (activities assisting value creation, e.g., administration) and Type 2 (pure waste in production, e.g., overproduction, transportation) (Vijay & Prabha, 2020). Some classify waste into seven categories, while others, like Ohno (1988), introduced unique waste categories.

Lean principles aim to continuously improve quality, delivery, safety, and cost through waste elimination and the establishment of a straightforward process flow to meet client demands (M. Z. M. Ismail et al., 2019). Lean manufacturing comprises five key components: manufacturing flow, organization, process control, metrics, and logistics. These components govern physical modifications, role identification, process monitoring, performance measurement, and material flow management.

In a lean manufacturing environment, expected outcomes include improved delivery performance, reduced manufacturing lead time, increased direct labor productivity, and a reduction in non-value-added activities (Feld, 2001). A pull production system, an ideal lean system, ensures production is initiated only when a customer request is received, minimizing overproduction.

A near-perfect Lean system achieves on-time deliveries without overproduction, emphasizing the importance of reducing overproduction, the most detrimental waste.

3. TOOLS LINE BALANCING

Balancing the line involves optimizing the work distribution to prevent such bottlenecks and make sure a smoother production process. Preparing of Production Lines activity equilibration: Production equilibrium refers to a situation where profit is maximized. Generally, at equilibrium level, any farm has the maximum level of output being produced as well as earning the maximum profit. We can analyze isoquant and is cost to understand the production equilibrium. Is cost refers to equal cost and it is the cost of purchase two factors named capital and labor. On the other hand, isoquant refers to equal quantity and it reveals the combination of input to get a quantity of output. We can have introduced Marginal revenue (MR) and Marginal cost (MC) to maximize the profit. To be noted, whether MR is not equal to Mc, producer can increase the production by changing the output as well as if MR >MC the supplier will cut back on production. It is also added that if MC<MR, the firm will continue to produce and at Mc= MR the production is maximum.

Arena Simulation Software: Arena is a simulation software used for modelling and analyzing various processes and systems. Indeed, it is a discrete event simulation and automation software. Basically this simulation software is used by government agencies, military and defense organization over the world to better plan policies, processes and operation. In the industries it has many advantages like improving visibility, exploring opportunities, fixing bottlenecks, reducing operating cost etc. Some disadvantages can also note like limited support, lack of real time simulation, version compatibility, high cost. Line balancing contributes to more efficient, productive and cost effective assembly process. It helps to maintain high quality standards and a motivated workforce.

How can we achieve line balancing: Line balancing minimises inconsistencies between and among employees and duties to maintain the desired run rate (Askin & Goldberg, 2001; Canh et al., 2013). Bottlenecks frequently emerge because the assembly line is difficult to balance, resulting in a significant number of lost resources such as work in process (WIP), overproduction, and waiting time. Consequently, Lean line balancing could assist in keeping work in process (WIP) running efficiently, through the line, with no or little delays between steps of the assembly process (Canh et al., 2013).

It is necessary to create a line balancing chart to identify the bottleneck points, along the line and to generate suggestions for improving the line (Lam et al., 2016). The operator-machine chart is a multiple activity chart that is used to measure the cycle time at the workstation, when there is collaboration between the operator and the machine. Furthermore, jobs at the workstation must be divided and thoroughly examined to determine which ones might be enhanced (Niebel & Freivalds, 1999). The total processing cycle time for all operations was recorded at each workstation individually. Furthermore, operations would be divided into two categories: value-added activities and waste activities (Lam et al., 2016).

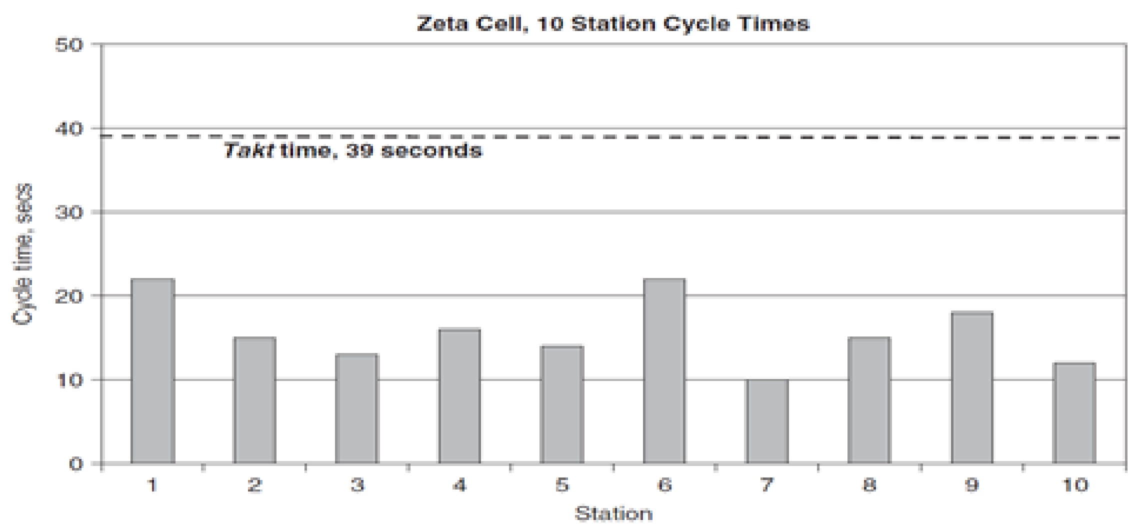

Figure 1: Zeta cell balancing graph (Wilson, 2010)

Three elements are obviously visible on the balancing chart (Figure 3): the amount of time wasted, the degree of balancing achieved, and the bottleneck. In the first place, the vertical gap between the Takt line and the station cycle time represents the waiting time, which symbolises the amount of time spent idle at that workstation. Subsequently, evaluating the heights of the bars, could briefly inform operators if the process is out of balance and what consequences rebalancing will produce. Lastly, the bottleneck has been identified as the highest bar, as previously stated.

It is shown visually in this line balance chart (Figure 3) how much time could be wasted, which is the gap between the top of the bar graph for each station and the Takt line that implies, if the output could be completed at the Takt rate was squandered. Given that the highest bar is 22 seconds, and the smallest bar is 10, the balance is skewed. Both of stations 1 and 6 are the highest, each 22 seconds in length. This is not a good balance; the cycle periods should be relatively close, and this is not the case. The bottleneck, which is the longest cycle time, happens twice in the process.

A similar study was carried out by Cuesta et al. (2020), in a case study of television assemblers. Based on the cycle time and Takt time of the television's case actions depicted in Figure 2.14, it is visible that the packing activity is performed above the Takt timeline, indicating that it is the activity, which establishes the pace of the process. Furthermore, the assembly activities 2 and 5 are both running below the Takt time as well.

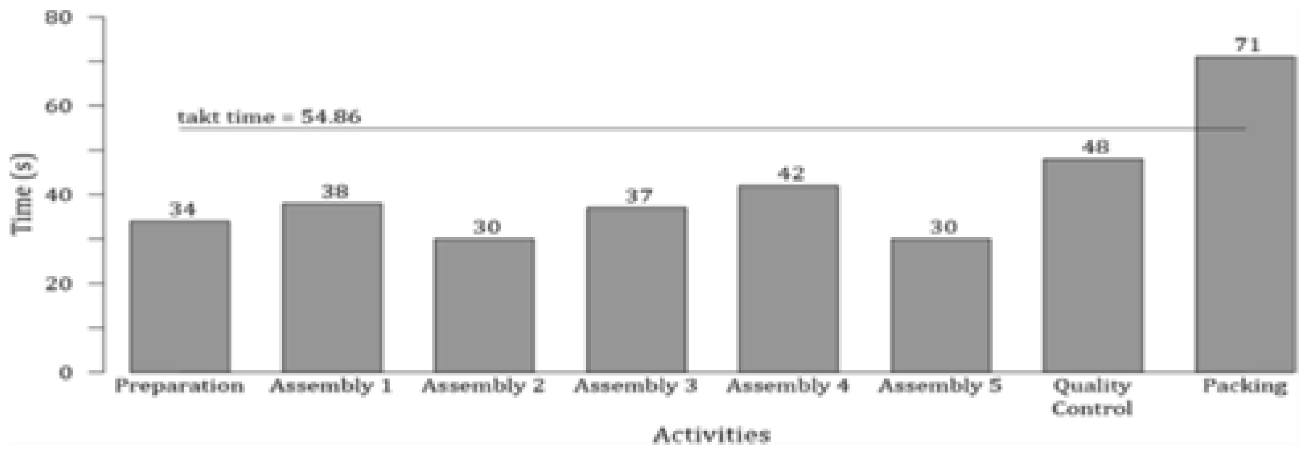

Figure 2: Cycle time vs. Takt Time

In consequence of the implementation of the process optimisation proposal, in Figure 5, the percentage of the bottleneck activity load was lowered, while the packing activity continued to set the pace for the rest of the manufacturing process. As a result of an evaluation of the workload that revealed that it was possible to regroup the activities so that the remaining time allowed for the same internal activities as the process required, the number of operators was decreased from nine to eight, and the number of stations was reduced from eight to seven.

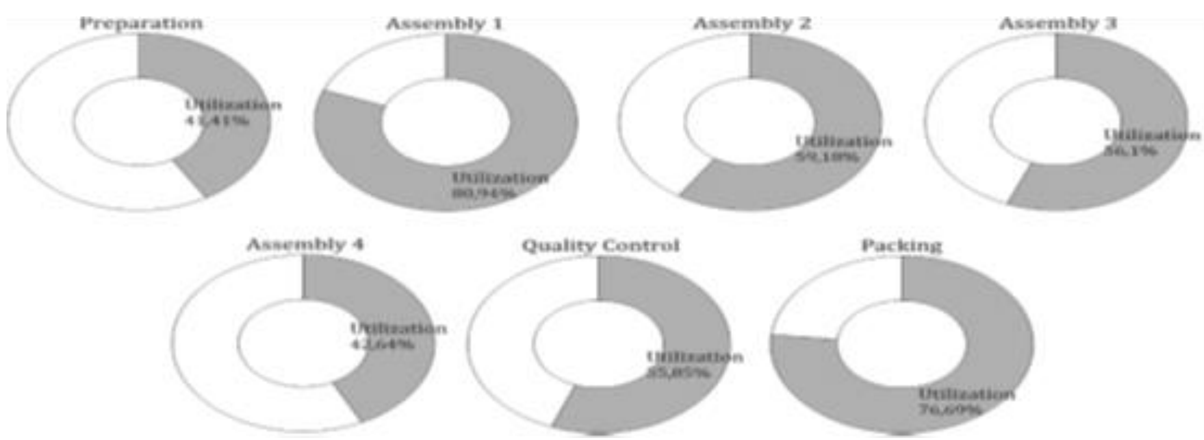

Figure 3: Percentage of use of the activities.

In the case it was determined that it would be more convenient to level them after conducting a workload study. An assembly station and, consequently, an operator was suggested to be eliminated, and the operations were divided among eight operators working at seven different workstations. The proposed change increased the productive capacity by 4.92%.

Most electronic assembly businesses place a strong emphasis on lowering costs, while simultaneously increasing customer value. The case study was carried out by deploying the lean line balancing tool to an electronics assembly line, as described by Lam et al., (2016). As seen in Figure 6, the distribution of cycle time at each workstation is depicted, with most of the waste time occurring at the ILP and FVT workstations. The line's waste time accounts for approximately 12.18% of total line time.

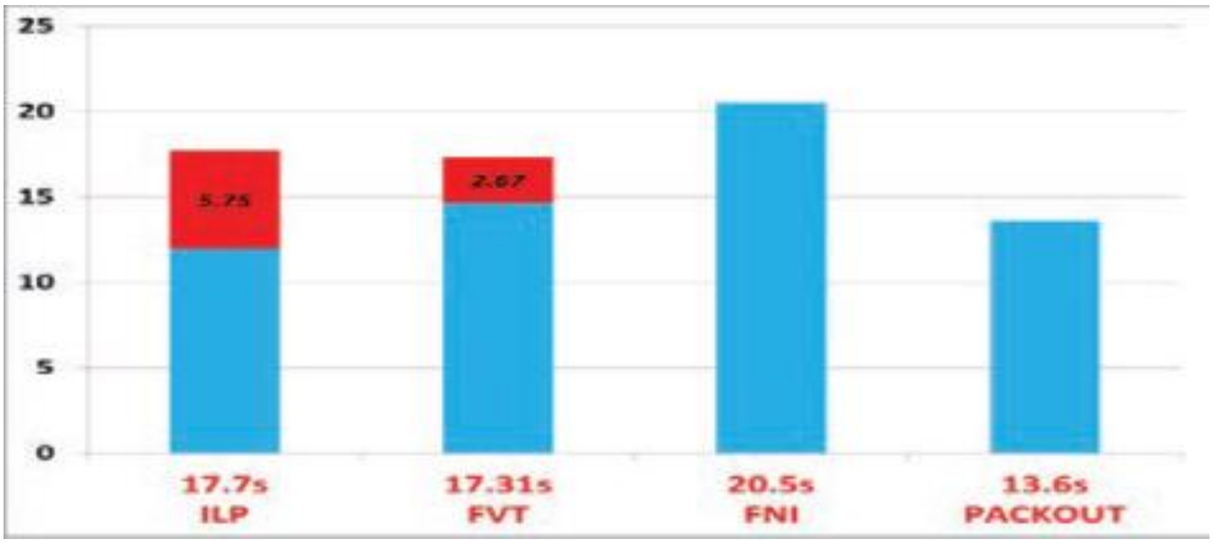

Figure 4: Workstation cycle time in seconds (**The red box indicates the waste of time*).

The production line capacity should be sufficient, since all workstation cycle durations are less than Takt time. As a result, there is a waste of resources (particularly human resources). The productivity of a fully occupied workstation is significantly higher than the needed one. Since the overall processing time is still less than the Takt time, it was determined appropriate for the ILP operator to send extra duty to the Pack out operator. The number of workstations has been decreased from four to three, and three operators can complete all of the tasks on the line. The overall quality of the electronics assembly line, as measured by the line balancing index, total labour effectiveness, productivity, and waste reduction, has been improved significantly.

4. METHODOLOGY

In this research, the tools covered in the discussion of the Lean approach implementation are those intensively involved in the production line of muffler for one of the product models, labelled as Body Line 1 (BLM) to indicate the specific process of muffler's body creation, which includes the work standardisation, work and time studies, the new approach of line balancing and the manufacturing cell design. The muffler production line was selected, due to the complexity of the process that involves multi-process operating systems, the demand variation, and the lengthy production line that requires constant observation, since bottleneck points often occurred along the process. The identified tools could be found practised in the said production line. Most of the obtained operational data that could be associated with these tools were usually organised in worksheets, where data connections were applied for dynamic changes, enabling changes in one worksheet to be reflected and replicated in the other documents.

In the studied production line (BLM model; BODY-1 line), there were ten workstations (arranged in a cellular format) needed to deliver the main body of the muffler, as opposed to the whole production of a complete muffler, from the collection of raw materials until the assembly process of the components with spot welding. The production process of a muffler's body was carried out in sequence, from the first to the tenth workstations. The list of the workstations is provided in Table 1.0.

Table 1.0: List of processes and workstations employed in BLM manufacturing cell

Workstation	Process	Description
1	Logo stamping	The stamping of customer's logo on the metal sheet
2	Body rolling	Metal sheet rolling to form the main body of the muffler
3	Spot weld	Spot welding of rolled metal sheet to form body
4	Flanging	Flange creation of the muffler
5	Tack weld	Tack welding of pipe perforator to muffler's body
6	Assy press	The assembly of baffles in the main body by press
7	Spot weld	Spot welding of baffle onto the main body
8	End seaming	End seaming of produced muffler 's body from the previous step
9	Tack weld	Tack welding of end plate to perforator
10	Spot weld	Spot welding of wire net to perforator

The basic form of time study was actually employed as well, as a tool to analyse the work elements in each workstation. However, this was done to balance the distribution of tasks, between the workstations involved with Lean line balancing. Other related data, including the operator movements, part transportation, and process cycle time were also included and documented appropriately by the company.

4. METHODOLOGY

All of the preceding applications of work measurements, as well as operator movements and process time analyses were useful for the following application of Lean line balancing. The line balancing was at the utmost priority, since the BLM production line was paced more by the operators than the machines. This is because, normally, rather than focusing on the machine capacity analysis to find out the requirement of machines needed in the line, it is more meaningful to provide the data from line balancing exercises (Hales et al., 2001). A specific operational document of the company that was related to line balancing existed under the title of "Time Study Summary: Current Situation Analysis". The document specifically defined the overall time outline of each operator in the production line and their corresponding study, as well as the line balance diagram that illustrated the time loss from each operator against the Takt time. The native state of the document is presented in Figure 5. However, for a better and easier analysis, the data was rearranged by separating the numerical information into Table 2.0, and the line balancing graph entitled "Line Balance Loss" (LBL) into Figure 6.

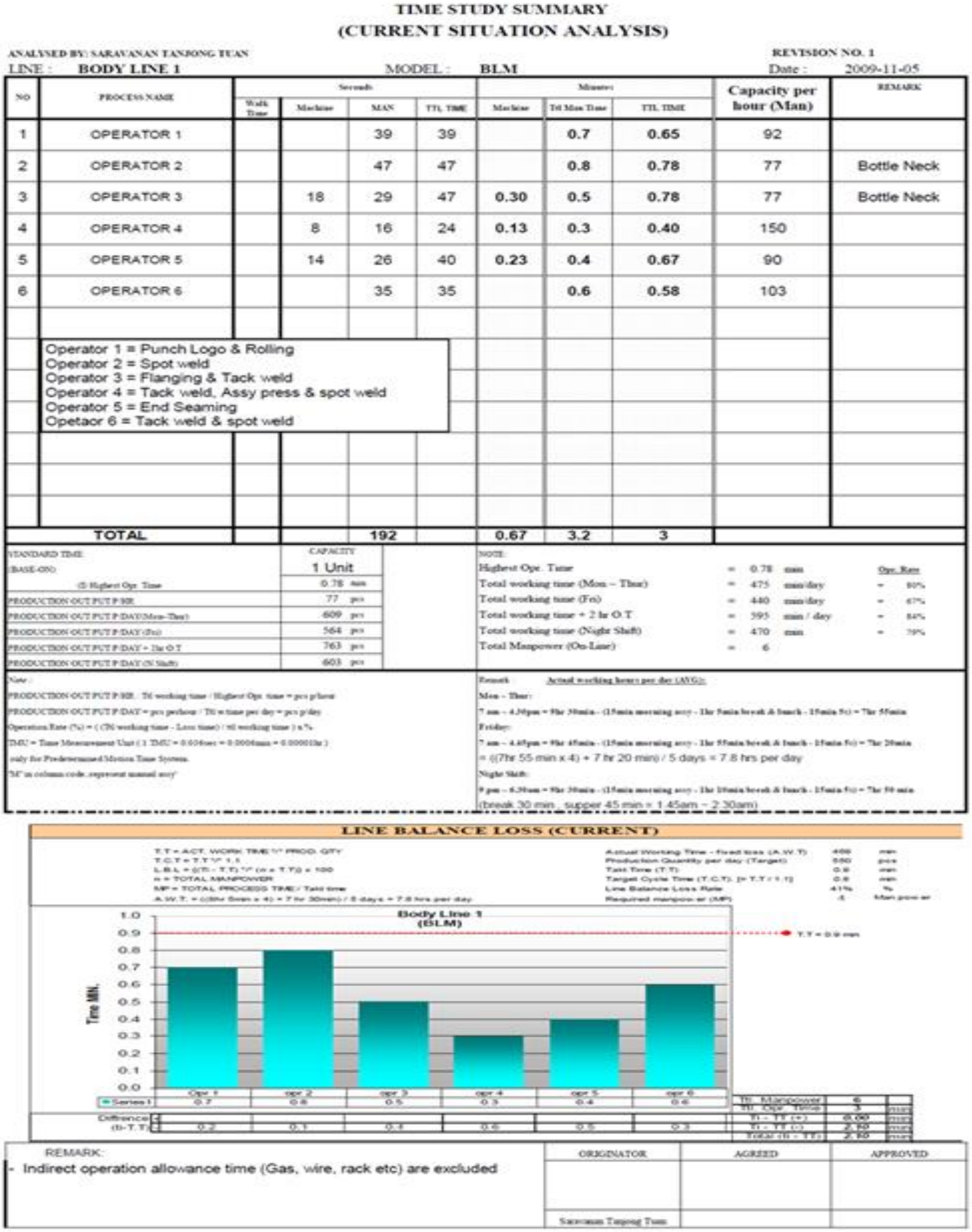

Figure 5: Time Study Summary (Current Situation Analysis) for BLM Production Line

Table 2.0: Time Study Summary of BLM muffler production line (Line-1)

Line: BODY LINE 1		Model: BLM			Date: YYYY-MM-DD		Revision No. 1	Analysis by: Saravanan Tanjong Tuan		
		Seconds				Minutes				
No	Process Name	Walk Time	Machine	Manual	TOTAL Time	Machine	Total Manual Time	TOTAL Time	Capacity per Hour (Man)	Remarks
1.	OPERATOR 1			39	39		0.7	0.65	92	
2.	OPERATOR 2			47	47		0.8	0.78	77	Bottleneck
3.	OPERATOR 3		18	29	47	0.30	0.5	0.78	77	Bottleneck
4.	OPERATOR 4		8	16	24	0.13	0.3	0.40	150	
5.	OPERATOR 5		14	26	40	0.23	0.4	0.67	90	
6.	OPERATOR 6			35	35		0.6	0.58	103	
TOTAL			**40**	**192**	**232**	**0.67**	**3.2**	**3.86**		

Standard Time: Based on:	Capacity: 1 Unit
(I) Highest Opr. Time	0.78 min
Production output per hour	77 pcs
Production output per day (Mon-Thurs)	609 pcs
Production output per day (Fri)	564 pcs
Production output per day + 2 h overtime	763 pcs
Production output per day (night shift)	603 pcs

Note:

Highest operation time 0.78 min	= **Opr. Rate**	
Total working time (Mon-Thurs) min/day	= 475 80 %	
Total working time (Fri) min/day	= 440 67 %	
Total working time + 2 h over time min/day	= 595 84 %	
Total working time (night shift) min	= 470 79 %	
Total manpower (on-line)	= 6	

Operator 1 = Logo stamping & rolling
Operator 2 = Spot welding
Operator 3 = Flanging & tack welding
Operator 4 = Assembly press & spot welding
Operator 5 = End seaming
Operator 6 = Tack welding & spot welding

Additional Note:

- Production output per hour: Total working time / Highest operating time = pcs/hour
- Production output per day = pcs per hour / total working time per day = pcs/day
- Operation rate (%) = ((Total working time – Loss time) / total working time) x 100
- TMU = Time Measurement Unit (1 TMU = 0.036 s = 0.0006 min = 0.00001 h)- only for Predetermined Motion Time System
- "M" in column code represents *manual assembly*

Remarks: Actual working hours per day (Averaged):

Mon – Thurs (7.00 am – 4.30 pm):
9 h 30 min – 15 min (morning assembly) – 1 h 5 min (break) – 15 min 5 s (lunch) = **7 h 55 min**

Friday (7.00 am – 4.45 pm):
9 h 45 min – 15 min (morning assembly) – 1 h 55 min (break) – 15 min 5 s (lunch) = **7 h 20 min**

Night shift (9.00 pm – 6.30 am):
9 h 30 min – 15 min (assembly) – 1 h 10 min (break) – 15 min 5 s (supper) = **7 h 50 min**
*Break duration: 30 min; Supper duration: 45 min (1.45 am – 2.30 am)

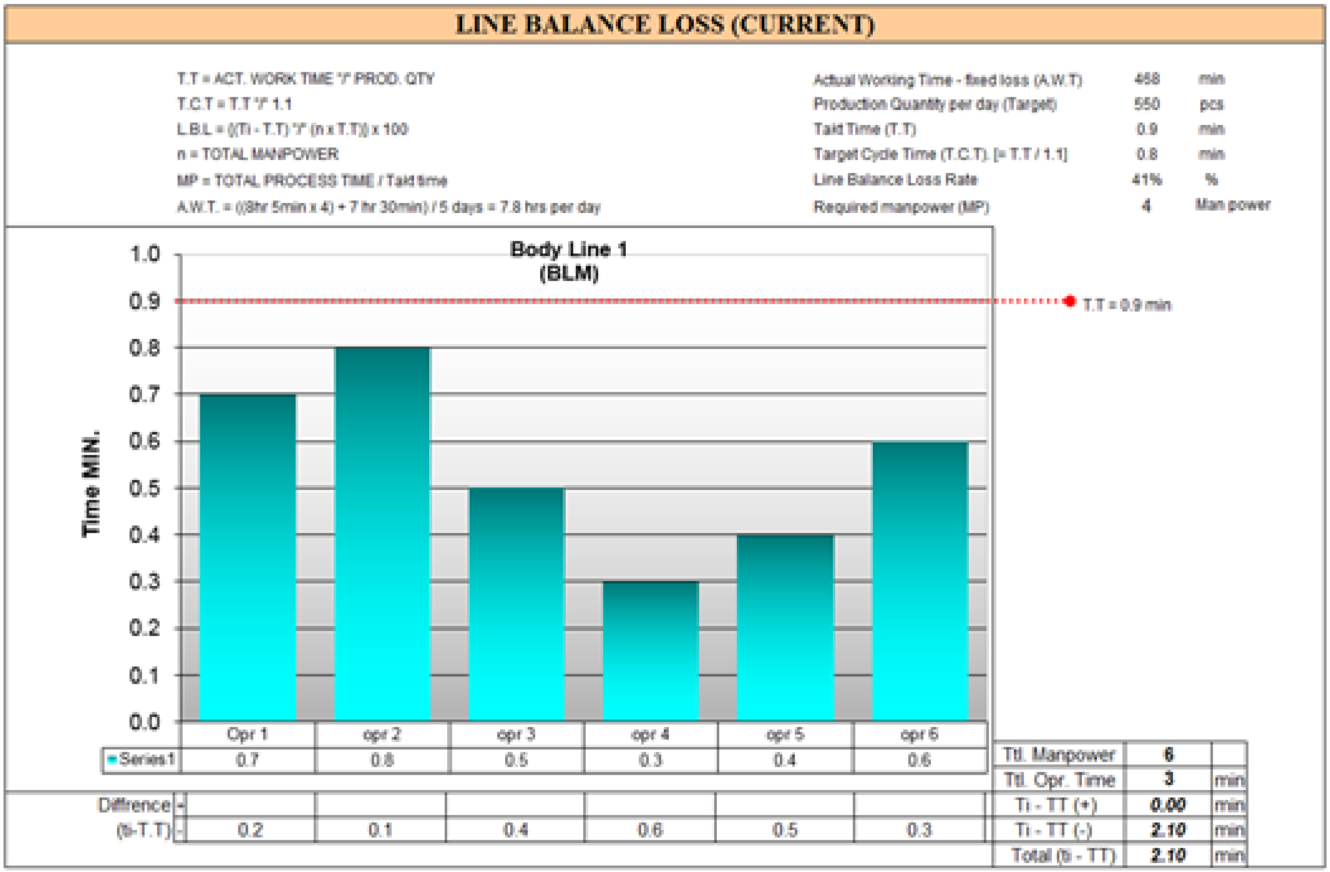

Figure 6: Line balance loss of operators employed at the BLM muffler production line (Line-1)

A multi-process operation system was employed where Operator-1, Operator-3, Operator-4, and Operator-6 were responsible for more than one processes. The summary in Table 2.0 shows the separation between manual and machine works. However, instead of displaying the time data in detail according to the work elements, the summary accumulated these times whenever an operator was found to be working in more than one processes. For instance, the data displayed for Operator-1, which manual and total times were recorded as 39 seconds, was actually the sum of logo stamping (ELE 1) and body rolling (ELE 2) cycle times at 7 seconds and 32 seconds, respectively. The similar calculating approach goes to Operator-3, Operator-4 and Operator-6. However, a discrepancy between data presented in the SWC sheet and Time Study Summary for Operator-6 can be spotted, where the former records is a sum of 36 seconds (Tack welding: 21 seconds; Spot welding: 15 seconds) while the latter shows 35 seconds, hence, a one-second difference in the data. The Time Study Summary was found to be utilising the time study's averaged time prior to rounding, adding 20.5 seconds of tack welding into 14.5 seconds of spot welding, hence the 35 seconds in the result. It appears that, all forms of computation that relate to the time study must always refer to the original work element data sheet, instead of the derivatives.

Another data being displayed in the summary is the hourly production capacity of each operator (Figure 4.28), which is the number of parts that can be manufactured within an hour of operation performed by the related operator. The quantity was defined by dividing an hour of time (60 minutes) by the total time of machine and manual works recorded. For instance, the capacity of Operator-1 at 92 parts per hour was obtained from dividing 60 minutes with the total time of 0.65 minutes and the hourly capacity of other operators can be calculated with the same approach. It should also be highlighted that, this calculated component is important in defining the bottleneck of the production line. In this case, the identified lowest capacity of the parts production was bottlenecked by the works performed by Operator-2 and Operator-3 at 77 parts per hour. The difference with the highest production capacity was relatively high, considering the maximum production rate by Operator-4 was at 150 parts per hour, almost twofold of the two former capacities

Table 3.0: Hourly production capacity (highlighted) of operators in BLM production line.

ANALYSED BY: SARAVANAN TANJONG TUAN REVISION NO. 1

LINE : BODY LINE 1 MODEL : BLM Date : 2009-11-05

NO	PROCESS NAME	Seconds				Minutes			Capacity per hour (Man)	REMARK
		Walk Time	Machine	MAN	TTL TIME	Machine	Ttl Man Time	TTL TIME		
1	OPERATOR 1			39	39		0.7	0.65	92	
2	OPERATOR 2			47	47		0.8	0.78	77	Bottle Neck
3	OPERATOR 3		18	29	47	0.30	0.5	0.78	77	Bottle Neck
4	OPERATOR 4		8	16	24	0.13	0.3	0.40	150	
5	OPERATOR 5		14	26	40	0.23	0.4	0.67	90	
6	OPERATOR 6			35	35		0.6	0.58	103	

The most critical part of the summary is the Line Balance Loss (LBL) chart that describes the manual workload of each operator, which also calculates the line balance loss of the production line (Figure 6). The chart provides the illustrative data on how the manual works were distributed among the operators. Hence, whenever a work balancing is needed, the chart could be used as a baseline before the redistribution of tasks and processes between the operators employed in the production line. The chart provides basic information of actual working time, targeted production quantity per day, Takt time, and targeted cycle time for operators. In the existing case, the actual working time after a reduction of fixed loss was 468 min/day, as opposed to 475 min/day in the Mon-Thurs work shift. Since, at that particular period the production target was set to 550 pieces/day, the Takt time can be calculated as 468 min/day divided by 550 pieces/day, i.e. 0.9 minutes in that particular period. This is depicted in the chart as a red horizontal line, which was proven to be helpful in calculating the line balance loss. An adjustment was made to the targeted cycle time by lowering the value to 90% capacity of Takt time by dividing the time with 1.1 factor. Hence, the 0.8 minutes was set as the target of the cycle time. The process cycle time should be synchronised externally to Takt time, making it possible for the production plant to satisfy the demand rate of the customer. However, this has practical limitations since sometimes problems can occur in the production line, such as machine failures, defective parts, and other cycle time associated problems. Since it was practically impossible to prevent these problems, the desired cycle time is usually shortened by adding the overall equipment effectiveness (OEE) factor into the equation (Wilson, 2010). In this instance, the production line introduced the equally OEE factor of 1.1 (equivalent to 90%) into their process cycle time.

The summary of the time study also provides the calculation of manpower requirement in the production line. The line balance chart summarised the calculation briefly as depicted in Equation

$$Manpower\ Requirement:=\frac{Total\ Manual\ Operation\ Time}{Takt\ Time}$$

(EG. EQUATION)

In this case, the minimum manpower requirement to anticipate the production demand, as displayed at the upper part of LBL chart, was calculated by dividing 192 seconds of total manual operation time with 54 seconds of Takt time, i.e., 3.56 which was rounded to 4 operators. However, it should also be noted that, manual work time was not the only component that needed to be considered when synchronising with Takt time. The machine work time also contributed to the accumulated process cycle time in each workstation. Hence, the manpower employed in a production line may not always be equal to the minimum manpower requirement. On the basis of the production output rate, the number of the operator could be adjusted, and the LBL chart should assist the distribution of the works.

In terms of productivity, the time wasted by each operator was described by the line balance loss calculation. The LBL chart shows graphically the loss from the time of manual work wasted by the operators in the production line, which is the distance from the Takt timeline (0.9 minutes) to the top bar graph of any operator. The LBL chart shows this data in the tabular format, at the lower area of the graph. The manual work time that exceeds the Takt time was labelled as Ti – TT (+), signifying the surplus of time spent when the cycle time of the operator is longer than the Takt time. Conversely, the manual work time performed lesser than the Takt time was labelled as Ti – TT (-), demonstrating the lack of time spent by the operators. To ensure that production output could fulfil customer demand, the process cycle time from each workstation must be equal to or lower than the Takt time. This is the reason why there were values recorded in the Ti – TT (-) slots but none for Ti – TT (+), since the production plant compelled the system to produce mufflers higher than the demand rate. The total difference between process cycle times and Takt time was the sum of Ti – TT (+) and Ti – TT (-), i.e., 2.10 minutes.

There are two approaches for line balancing to be implemented in a production or assembly line. The first one is the utilization of this method to ensure proper distribution of tasks across the available workstations in the production line. This is particularly common when one operator is assigned to only one workstation or process, where, to align with Takt time, any excessed tasks in certain workstations shall be redistributed to other underutilized workstations. The second one is to distribute tasks among the assigned operators for the production line. In this approach, instead of redistributing tasks beyond Takt line across the available processes (workstations), the tasks shall be redistributed among the operators assigned in the said production line.

CONCLUSIONS

Making management decisions can be aided by the line balance loss analysis. It offers advice on the necessary steps to be made and presents a clear picture of the existing process efficiency. This study gives decision-makers the knowledge they need to make informed decisions, whether the objective is to increase productivity, decrease waste, or streamline operations. This method differs from others in that it can support decision-making for process improvement with or without additional funding. It aids management in locating areas where process improvements can be made without expending a lot of money. Businesses can significantly increase productivity and cost-effectiveness by concentrating on maximizing their current resources and getting rid of inefficiencies. The line balance loss analysis also helps the organization save money on expenses. Organizations can reduce unforeseen costs related to waste, rework, and excessive resource use by detecting and fixing process inefficiencies. The bottom line of the business is directly impacted by these cost savings, which also boost overall profitability. In conclusion, the new method of line balance loss analysis offers thorough perceptions into the general process state. The management is given the freedom to decide whether or not to invest in process improvement. Utilizing this analysis technique, businesses can improve productivity, cut expenses, and contribute to long-term success.

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