Truck Assembly Line Reconfiguration to Reduce Cycle Time with Lean Manufacturing Approach in the Indonesian Automotive Industry

J Yudhatama¹ and I M Hakim²

¹ ²Department of Industrial Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia
E-mail : jerry.yudhatama@ui.ac.id, inakimhakim@eng.ui.ac.id

Abstract. The automotive industry is one of the industries that plays a major role in Indonesia's revenue sources, one of which is in meeting daily needs, especially for transportation and logistics. This causes the growth of truck production targets each year and has become one of Indonesia's focus to target 1.29 million trucks produced in 2020. This study aims to minimize production time with the optimal number of workstations to minimize costs that will come out for increasing production capacity in truck assembly lines in Indonesia. The study was conducted with a lean manufacturing approach to analyze the waste contained in the assembly line. The study began by calculating time for each work using the time study method. The time obtained is then inputted to the mixed integer linear programming mathematical programming model developed in the LINGO 17.0 software. The result of data processing in the LINGO 17.0 software is the allocation of each job to the new workstation to get the production cycle time in accordance with the production takt time, and also the total idle time of the new assembly line.

1. Introduction

The lean manufacturing approach to assembly lines is one important factor that all industries should consider. This is because the lean manufacturing approach can have a major impact on the sustainability of a company. This is also supported by several research [1] that has been conducted.

Indonesia has a large market share in the ASEAN automotive manufacturing industry. The manufacturing industry is one of the hearts of the Indonesian economy itself with a contribution to Indonesia's Gross Domestic Product (GDP) which continues to increase every year. This is also supported by direct directions from the government to increase Indonesia's annual truck production target. With the continued growth of the automotive industry in Indonesia, especially for light trucks and heavy-duty trucks, this will create new problems, namely that truck manufacturers must increase their vehicle production capacity to meet increasing demand. Therefore, as a manufacturing company, they are required to increase efficiency in their production system in order to achieve the desired production capacity without having to pay additional costs to adjust production to their capacity.

The imbalance of workloads in terms of cycle time at each workstation is also one of the causes of inefficient assembly lines in Indonesian automotive companies. The cycle time that is still above the production takt time will have an impact on not achieving the desired production target. Therefore, as a follow-up to the lean manufacturing approach used to analyze waste, a mathematical model was
developed in the form of a linear program to balance cycle time at each work station so that the cycle time of each work station can be reduced to below the takt time limit while minimizing idle time. The research will conduct a time study to find the standard time for each task to be included as a variable in the developed mathematical model and analyze how changes will occur in the assembly line.

2. Literature Review

2.1. Lean Manufacturing Approach

Lean, the Japanese concept of manufacturing dynamics, is widely practiced by organizations to increase productivity, reduce waste and address environmental impacts. These efforts have evolved in industrial and academic fields over the last few decades [3]. Lean manufacturing has five key principles of lean thinking (LT) which were introduced to address the various challenge occurs within and between business units from the differences in business culture and management thought process. The key principles in LT are (1) define value from the customer perspective, (2) identify the value streams, (3) make the value flow, (4) implement pull-based production, and (5) continuously strive for perfection. The key goal of those principles is to establish a perfect value stream by continuously identify and eliminate activities that are considered waste and focus on activities that truly create value [4,5].

Within the lean principle, the term waste reduction is also known, where reducing waste in terms of the seven main wastes in the industry namely inventory, defect, over-production, over-processing, transportation, waiting, and motion.

2.1.1. Waste of Waiting. Waste of waiting is directly relevant to flow and it occurs when time is not being used effectively [6]. This can be caused by bottleneck that occurs between workstations so that the product in the production line must wait for the next workstation to finish its work.

2.2. Linear Programming

Linear programming is an optimization method applicable for the solution of problems in which the objective function and the constraints appear as linear functions of the decision variables. The goal of linear programming is to find a best feasible solution, as measured by the value of the objective function in the model [7]. The constraint equations in a linear programming problem may be in the form of equalities or inequalities [8]. Mixed Integer Linear Programming or MILP is the optimization of problems that only use linear functions and limited to some integer variables. Two general approach to complete MILP problem is to use the Branch-and-bound method or Cutting-plane method [9]. MILP is often used for system analysis and optimization as it presents a flexible and powerful method for solving large, complex problems such as the case with industrial symbiosis and process integration [10].

3. Research Method

There are 31 lean manufacture drivers, where if reviewed carefully and by developing the strategies to implement them, it will be easier for practitioners to implement LM in their companies [11]. Assembly Line Balancing (ALB) aims to determine the allocation of works to the order of work stations, so that each job is allocated to one workstation, and in order of job sequence that needed to be completed first and also measure and optimize several performance factors such as minimizing the number of work stations [12]. Based from the lean manufacturing approach, obtained waste that still exists in the assembly line of the research object is waiting where idle time at each workstation is still high because the cycle time of each work line assembly line is not yet balanced. This also inhibits the company from achieving its production targets. Therefore, the company's production takt time is calculated which is then used as one of the optimization calculation parameters.
3.1. Data Pre-processing

The data pre-processing stage starts from illustrating the assembly line to get the sequences of the truck assembly line. Then, followed by a time study to calculate the standard time of a task time that obtained from the observations by taking into account the performance factors of the workers and adding allowance time. The time study formulation expresses as follows [13]:

\[
NT = (OT) \times \frac{RF}{100}
\]  

\[
ST = NT \times \{1 + \text{Allowances} \ (\%)}
\]

Time study is one method for calculating the standard time of workers who are familiar with the job, using methods, equipment and equipment as well as the environment and working conditions under certain conditions [14]. This standard time is then included as one of the parameters in the mathematical model as the execution of time \(t_i\).

Figure 1. Sequence of truck assembly line

Figure 1 illustrate the task sequences of the assembly line to see the work sequences rules that must be met. There are 46 jobs in this assembly line, where each job has a sequence relationship with each other. This work sequence is then used as data in the mathematical model.

| Notation | Definition |
|----------|------------|
| \(V\)    | Set of tasks                          |
| \(c\)    | cycle time                              |
| \(k\)    | Set of workstations                      |
| \(KD\)   | Set of definite workstations            |
| \(KP\)   | Set of probable workstations            |
| \(R\)    | Set of direct precedence relations      |
| \(\bar{m}\) | The upper bound on the number of stations |
| \(t_i\)  | The execution time of task \(i \in V\) |
| \(\delta_k\) | Idle time of workstations \(k\) |

Table 1 defines the notations and parameters that will be used in the mixed integer linear programming mathematical model to be developed.
3.2. Mathematical Modelling

The mathematical model of assembly line itself has been developed within a research conducted [11]. Then the model modified to adjust the actual research condition and reach the amount of cycle time that matches the daily demand and also to increase the efficiency of the assembly line by minimizing the station idle time. This study is using optimization software LINGO 17.0 to run the model iteration. First, the steps taken are determining the variables, sets and parameters that will be used in the mathematical model equation. The objective function of this model is to minimize the total idle time of the assembly line (3) so that the efficiency of the assembly line remains high with the constraint of cycle time of each station not exceeding the production takt time. Constraint set (4) ensure tasks are allocated to one workstation. Constraint set (5) set precedence relationship between task. Then, the cycle time parameter is set to 192 seconds based on the production takt time of the research object which will accommodate the 150 units per day target and also capture the idle time in each workstation (6) (7) (8). Constraint set (9) ensure sequential use of work stations. Constraint set (10) defines idle time decision variable. For \( i \in V \) and \( k \in FS_i \) a binary variable is also created to indicate whether there is a job assigned to the station defined as \( x_{ik} \) and for \( k \in KP \) a binary variable is created to indicate whether there is work assigned to that station that defined as \( u_k \).

The mathematical formulation can be expressed as follows:

FE: \[ \text{min } I = \sum_{k \in K} \delta_k \] (3)

Subject to:

\[ \sum_{i \in FS_i} x_{ik} = 1 \quad \forall i \in V \] (4)

\[ \sum_{i \in FS_i} k \cdot x_{ik} \leq \sum_{i \in FS_j} k \cdot x_{jk} \quad \forall (i, j) \in R \] (5)

\[ \sum_{i \in FT_k} t_i \cdot x_{ik} + \delta_k = c \quad \forall k \in KD \] (6)

\[ \sum_{i \in FT_k} t_i \cdot x_{ik} + \delta_k \leq c \quad \forall k \in KP \] (7)

\[ \sum_{i \in FT_k} t_i \cdot x_{ik} + \delta_k = c \cdot c (u_k - 1) \quad \forall k \in KP \] (8)

\[ u_{k+1} \leq u_k \quad \forall k \in KP \{m\} \] (9)

\[ \delta_k \geq 0 \quad \forall k \in K \] (10)

After all mathematical models have been translated into the LINGO 17.0 programming language, standard time data for work activities and work order rules are input to the mathematical model as data sets, then the model is run and the optimal total idle time results in the status solver window.
4. Result and Discussion

Based on the results of data processing using the method of mixed integer linear programming with the help of LINGO 17.0, mathematical models can be verified and validated and also we can achieve 'global optimum' state of solution, from this result we can also design of a new job allocation for each work station with an adjusted cycle time so that all workstations have new cycle time which below 192 seconds and minimizes total idle time according to the objective function of the mathematical model.

From Figure 2 it can be seen that the need to add one work station to meet the takt time requirements (yellow bar for the current actual cycle time and blue bar for optimized cycle time). After making repairs, the total idle time from the assembly line becomes 260 seconds. Figure 3 shows the new work sequence at each work station and also the work at the new work station, by applying this sequence of work, a new cycle time will be obtained on the FC 8 assembly line under 192 seconds per unit. This reconfiguration also resulted in an increase in the number of production of 10 trucks per day.

Figure 3 shows that the tasks that are rearranged must also fulfill the sequence order of work so that the truck assembly process can continue in the order of installing parts. This study also carried out several schemes of reducing cycle time, namely 5% and 10% below the takt time, and the results show that every 5% reduction in cycle time will result in an addition of one workstation. This is a trade-off that must be considered properly by companies because the costs that come out will also affect their level of production.
Figure 3. Optimization result of the truck assembly line

5. Conclusion and Future Work
In this study, we analyze waste that occurs in Indonesian automotive manufacturing company, based on the lean manufacture approach. Waiting is one of the wastes that needs to be eliminated. This study developed a mixed integer linear programming (MILP) to interpret the actual condition and to reduce cycle time while minimizing total idle time of an assembly line to increase line efficiency and decrease the assembly line cycle time from 205 seconds to 192 seconds with one additional workstation while minimizing assembly line's total idle time.

Based on the results of this study, the following suggestions for future research are to conduct an analysis of non-value-added work to see which work can be eliminated or reduced in time and consider the costs that will be incurred to carry out additional workstations.

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References
[1] Yadav G, Luthra S, Huisingh D, Mangla S K, Narkhede B E and Liu Y 2020 Development of a lean manufacturing framework to enhance its adoption within manufacturing companies in developing economies J. Cleaner Production 245 p 118726
[2] Santos Z G D, Vicira L and Balbinotti G 2015 Lean Manufacturing and Ergonomic Working Conditions in the Automotive Industry Procedia Manufacturing 3 pp 5947–54
[3] Verrier B, Rose B and Caillaud E 2016 Lean and Green strategy: The Lean and Green House and maturity deployment model J. Cleaner Production 116 pp 150–6
[4] Thangarajoo Y and Smith A 2015 Lean Thinking: An Overview Industrial Engineering and Management 04(02)
[5] Sundar R, Balaji A and Kumar R S 2014 A Review on Lean Manufacturing Implementation Techniques Procedia Engineering 97 pp 1875–85
[6] Wahab A N A, Mukhtar M and Sulaiman R 2013 A Conceptual Model of Lean Manufacturing Dimensions Procedia Technology 11 pp 1292–98
[7] Hillier F S 2015 Introduction to operations research (New York: McGraw-Hill Education)
[8] Rao S S 2020 Engineering optimization: theory and practice (Hoboken, NJ, USA: John Wiley & Sons, Ltd.)
[9] Taha H A 2007 Operations research: An introduction (London: Pearson Education Limited)
[10] Kantor I, Robineau J, Butun H and Marechal F 2020 A Mixed-Integer Linear Programming Formulation for Optimizing Multi-Scale Material and Energy Integration *Frontiers in Energy Research* 8(0049)

[11] Esmaeilbeigi R, Naderi B and Charkhgard P 2015 The type E simple assembly line balancing problem: A mixed integer linear programming formulation *Computers & Operations Research* 64 pp 168–77

[12] Ponnambalam S G, Aravindan P and Naidu G M 2000 A Multi-Objective Genetic Algorithm for Solving Assembly Line Balancing Problem *The Int. J. Advanced Manufacturing Technology* 16(5) pp 341–52

[13] Hartanti L P S 2016 Work Measurement Approach To Determine Standard Time In Assembly Line *Int. J. Management and Applied Science* 2(10) pp 192–5

[14] Taylor F W 1997 *The Principles of Scientific Management* (United States: Dover Publications)