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Assembly line design using a hybrid approach of lean manufacturing and balancing models

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ABSTRACT
This manuscript presents a method to design automotive production assembly lines that integrate lean manufacturing approaches and line balancing algorithms. In this work, we develop a clustering algorithm and task mutuality index for the assembly tasks to redesign and rebalance an assembly production line with a fixed layout and machinery. Moreover, we consider the product demand variability and the introduction of new product models. This paper describes the current and the future states of an automotive engines assembly production line using quantitative performance parameters and assembly tasks content flow charting, along with the analysis and results obtained from the proposed approach. The results show a reduction in required modeling and optimization efforts and a reduction in the required time to generate a feasible redesign of an assembly line while reaching the required takt time based on the demand forecast.

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1. Introduction
Several industries utilize lean manufacturing to increase the value of their products and reduce all form of waste. Assembly lines design and balancing are one of the challenging aspects of automotive production lines. The initial assembly line design focuses on creating feasible layouts and work contents for the mass production of standardized parts (Uddin & Lastra, 2011). However, the simple introduction of specialized products with variation in tasks can shift the line balance and affect the production takt time. This variability requires a rebalancing every time a new part or family of parts are introduced into the system. This design challenge is persistent when the demand for new product families is low.

Most of design standardization concepts deal with the standardization of components, module interface or assembly process (Siddique, Rosen, & Wang, 1998). The scope of this paper deals with the standardization of assembly tasks or work content on the assembly station to classify the products families. The standardization of the assembly process necessitates assigning the assembly tasks to a station without changing the tools or the assembly sequence of the components.
Assembly line balancing belongs to the optimization models area where one or multiple optimization objectives are to be met. Often, researchers dealt with line balancing from the mathematical perspective and with initial assumptions that the line design can be changed or altered based on the optimization results. However, redesigning and changing the assembly line are costly and time consuming (Qattawi, Mayyas, Abdelhamid, & Omar, 2013). The high number of constraints due to fixed design elements such as layout or number of station carriers can often lead to optimization results that are not valid, reducing the solution space, and leading to an unsolved problem. The presented approach in this manuscript introduced lean manufacturing principles as an initial phase to reduce modeling complexities and reduce design constraints. The second phase includes optimization modeling to achieve the required takt time of an automotive assembly line.

The following sections discuss the literature review and the developed methodology, which is presented by two phases, each is subdivided into steps. The section four discusses the results and followed by the conclusion in section 5.

2. Literature review

Lean manufacturing is increasingly under use to redesign and improve assembly lines designs through value stream mapping (VSM) (McDonald, Aken, & Rentes, 2002; Rahani & Al Ashraf, 2012; Serrano, Ochoa, & Castro, 2008; Seth & Gupta, 2005; Vinod, Arvind, & Somanaathan, 2011) and Kanban system approach (Álvarez, Calvo, Pení a, & Domingo, 2008; Cherrafi, Elfézazi, Chiarini, Mokhlis, & Benhida, 2016). Such tools proved their use and ability to be combined with simulation tools (Abdulmalek & Rajgopal, 2007; McDonald et al., 2002), as well. A key to the success of the lean manufacturing principles is the ability to combine the applied tools with assessment criteria (Karim & Arif-Uz-Zaman, 2013a; Vinod et al., 2011). Examples of quantitative assessment criterion are the reduction in defects percentage, reduction in the delivery time, inventory reduction, increase in labor and machinery utilization, reduction in floor space, utilization improvement in quality, and reduction in takt time (Chang, Pan, Xiao, & Biller, 2013). Most of the lean manufacturing principles can be implemented in the assembly lines settings in comparison with the batch or job shop floors (Todorova, 2013; Yin, Stecke, Swink, & Kaku, 2017). Several studies implement a lean-based assembly line optimization methodology to reduce the time loss due to factors like machine failures, inventory shortages, setup times, and material handling (Nallusamy & Saravanan, 2018; Rane & Sunnapwar, 2017). Nagi, Chen, and Wan (2017) used data collected from VSM and Pareto chart to improve productivity in a multimodel assembly line and enhance the assembly line performance.

Most assembly line balancing is required to meet two major constraints: the desired takt time and a required throughput (Cochran, Hendricks, Barnes, & Bi, 2016). The takt time can be correlated to the demand rate. As the customer demand changes, the takt time also changes which requires a rebalancing of the production line (Chang et al., 2013). Takt time is defined as the ratio of total time per shift to demand rate per shift. Takt time requires that each station takes the same exact time to perform all assigned tasks on the product, then the product should move to the next station. Zhu, Hu, Koren, and Marin (2008) evaluated the complexity of mixed-model assembly system and optimized the assembly systems performance. It has been proved that production
lines that utilize low inventory and repair buffers consistently outperformed mass production plants (Macduffie, 1995).

An assembly line balancing (ALB) problem involves assigning assembly tasks among stations in such a way that each station takes equal takt time (Boysen, Fliedner, & Scholl, 2007). Line balancing approach improves the effectiveness, efficiency, and productivity of production facilities to meet consumer demand and stay competitive in the market (Sridhar, Anandaraj, & Santhosh, 2017; Yagmahan, 2011). Another objective of the line balancing algorithms is to assign elements to stations by strictly adhering to all precedence constraints and to minimize the idle time associated with a set of station assignments (Thomopoulos, 1970). According to the comprehensive literature review by Sivasankaran and Shahabudeen (2014), the ALB problems are broadly classified into eight types based on the number of models (single mode or mixed model), deterministic or stochastic nature of task times, and the shape of the production line. The shape of the production line includes straight lines and U-shaped lines (Miltenburg, 2002).

A mixed-model line produces different products with a pre-determined sequence based on demand and assembly line capabilities (Bukchin, Dar-El, & Rubinovitz, 2002) and helps the manufacturers to offer a variety of products in a timely and cost-effective manner (Sparling & Miltenburg, 1998). One of the earliest approaches to solve a mixed model assembly line balancing (MALB) problem uses a heuristic method to assign work elements to the stations and a Monte Carlo simulation to sequence these models in the line (Thomopoulos, 1967). Similarly, Kuo, Huang, Wei, and Tang (1999) used colored time Petri net (CTPN) to balance the MAL using the concept of several levels and multiple modules in each level. The objectives of MALB problems include minimizing the number of stations, cycle time, station idle time, and weighted smoothness index (Akpinar, Elmi, & Bekta, 2017; Erel & Gokcen, 1999; Gokcen & Erel, 1997, 1998; Karabat & Sayn, 2003; Ozcan & Toklu, 2009; Sparling & Miltenburg, 1998). The maximizing objectives include weighted line efficiency and capacity utilization (Ozcan & Toklu, 2009; Yagmahan, 2011). Researchers considered one or more of the features like the mixed models, zoning, assignments, two-sided v/s single sided assembly lines, parallel workers etc. (Abdullah Make, Ab Rashid, & Razali, 2017; Alghazi & Kurz, 2018; Delice, Aydogan, Ozcan, & Ilkay, 2017).

Researchers classified the MALB problem as NP-hard and devised various heuristic to solve the model. Some of the common heuristic models include COMSOAL (McMullen & Frazier, 1997), ranked positional weight heuristic (Gokcen & Erel, 1998), hybrid genetic algorithm (Noorul Haq, Rengarajan, & Jayaprakash, 2006), simulated annealing (Ozcan & Toklu, 2009), and ant colony optimization (Yagmahan, 2011). Some authors developed an exact algorithm using benders decomposition (Akpinar et al., 2017) and integer programming methods (Gokcen & Erel, 1998). Similarly, some researchers used simulation techniques such as Monte Carlo simulation (McMullen & Frazier, 1997; Thomopoulos, 1967) and tools like Probalance (Boivie & HÖ Glund, 2008). Even though most of the problems considered deterministic models, some authors considered stochastic values of task duration or uncertain processing time and applied goal programming techniques (McMullen & Frazier, 1997) and fuzzy heuristic (Hop, 2006) to solve the MALB problems. While most of the authors considered straight line models with one-sided assembly lines, some authors
considered the U-line assembly line (Sparling & Miltenburg, 1998) and two-sided assembly lines (Ozcan & Toklu, 2009).

Based on the above literature review, the majority of the literature use complex algorithms for assembly line design. To the best of our knowledge, we find no literature that uses a clustering algorithm, task mutuality index for assembly tasks, and offers a method to redesign and rebalance an assembly production line with a fixed layout and machinery.

3. Methodology

In this work, we introduce a two-phase methodology that improves the assembly line balancing and reduces the computational effort and the need for a complex and comprehensive line balancing mathematical models. The first phase relies on solutions based on lean manufacturing principles to improve the assembly line performance and reduces constraints for the line balancing optimization model. The second phase includes finding solutions to an assembly line balancing problem to achieve similar takt time based on the forecast demand values. We use an ALB algorithm (Sly & Gopinath, 2005), an practical, to assign tasks to stations that yields a takt time of 60 seconds to generate minimum required stations. This work was implemented within a manufacturing plant in the United States for automotive parts assembly. The identity of the organization is protected; however, we shall refer to the plant as Auto Engines (AE).

The followed approach in this manuscript can be divided into three steps: (1) decomposing the work content into task elements, this is conducted by observing the motion and study analysis of assembly tasks (Karim & Arif-Uz-Zaman, 2013b), (2) eliminating waste in terms of tasks that can be performed offline to reduce the takt time and consequently reduce the number of stations and workers (3) balancing the available tasks to different stages using the ALB algorithm.

We use flowcharting tools that assist lean manufacturing by collecting product and production data (Drohomeretski, Da Costa, de Lima, & da Rosa Garbuio, 2014) and provide a visual design to the major performance parameters under consideration and document current layout. In this work, the authors utilized flowcharting to represent the work content flow and provide more insight into the layout restrictions.

3.1. Understanding the current state of the assembly line

The current AE assembly line has 30 engine models and will have a total addition of 22 new engine models. Figure 1 illustrates a flowchart layout of the current state of the AE assembly line. The flowchart is used to illustrate the sequence of the work content and the traveling phases. The flowchart is not to scale and it is not used to reflect on the layout actual area. However, flow charting used in this work represents the actual shape of the assembly line of having two U-shaped segments attached to a finished engine designated area and empty engine carrier parking area, see Figure 1.

There are three different zones where the stations are located due to the physical layout. The first zone is equipped with flexible path carriers and it can have up to 14 stations indicated with the first U-shaped segment containing stations 1–12. The second zone extends as a normal straight line-shaped assembly line and in the current state contains stations 13–23 as indicated in the flowchart in Figure 1. The third working zone is
extending vertically with respect to the second zone and contains stations 24–27. The current finished engine area is assigned within the assembly line area due to space restrictions. The parking station of empty engine carriers is shown in a green color in Figure 1, it is fixed due to guided tracks that already established over the whole line and is not under consideration for redesigning by AE management. The line is unbalanced for the demand of the 30 engines with a total takt time per station between 10 and 106 seconds, with often bottlenecks in stations 15–21. The assembly line worked two shifts of 8 hours with a 1-hour break each. The introduction of different models disturbs the performance of the assembly lines. The fluctuations in takt time will lead to inefficient utilization that is reflected in having stations with high idle time for the engines with low work content. While other stations are over-tasked when an engine model has many tasks to be performed.

To understand the time content per station that will be affected by introducing the new engines, we analyzed the takt time fluctuation per station. The 52 engines demand is assumed to be based on the demand forecast for the coming three months with the introduction of the new engines models. Figure 2 illustrates the time difference between the engines with high work content and the engines with lower one per station. The study showed a high fluctuation in takt time per station that can be around two minutes for the line’s stations 25–27. In addition, stations 1–4 and 13 have standardized work content for most of the engines that lead to zero-time fluctuations among the engines.

### 3.2. Phase 1: lean manufacturing principles

There are several lean manufacturing concepts suited to be applied in the settings of the assembly lines. In this work, we focus on three principles to improve the assembly line with the least changes to the overall physical layout. Those are Heijunka (production leveling), Muda elimination, and supermarket.
The first step is to list the Motion & Time Study (MTS) data for all engine models (Mundel, 2013). The investigation concludes 600 total tasks that workers can perform on the assembly line. In MTS, the work content for each engine is divided into precise and measurable functions with designated time. For example, the MTS study to tighten the transfer case for a specific engine model $KXC_1$ is broken into tasks and given time for each as shown in Table 1.

### 3.2.1. Step-1: constraints of tasks sequence on the engine line

One major challenge in balancing the assembly line is the precedence of tasks. In this work, the precedence is analyzed based on clusters of assembly phases. We clustered the tasks into assembly phases; all the tasks within one phase should be done in the same station or two successive stations. There are 20 common assembly phases for any engine model assembled on the line. However, for each assembly phase, we still need more investigation to determine the sequence of tasks within that phase. Once the assembly phases are established, we introduced a precedence index, $P_{ij}$ to determine the precedence between phases $i$ and $j$ given in Equation (1).

$$P_{ij} = \begin{cases} 1, & \text{if phase } i \text{ must come before phase } j \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

We used the MTS data to create $P_{ij}$ matrix for all phases. The MTS data sets are generated to inherently include major precedence requirements. The 20 assembly phases are listed in Table 2 with the immediate predecessors.

### Table 1. MTS data established for engine model $KXC_1$.  

| Task                              | Time in Minutes |
|-----------------------------------|-----------------|
| Pick transfer case and take to assembly station | 0.3             |
| Join transfer case to transmission | 0.2             |
| Insert 1 bolt in transmission case | 0.15            |
| Insert and tighten 4 bolts to transfer case | 0.367           |
| Tighten transfer case             | 0.06            |

![Figure 2. Takt time fluctuation per station.](image-url)
3.2.2. Step-2: introduction of supermarkets

Supermarkets are buffer or storage areas for products that are ready to be shipped or to be used (Abdulmalek & Rajgopal, 2007; Álvarez et al., 2008; Rother & Shook, 2003; Todorova, 2013). We investigated the complete 600 tasks for the possibility of being offline/online tasks, and we assigned a binary number of 0 or 1 for each task in the MTS system. If a task can be done offline without having the engine model present, then it is assigned a zero number. That is true for kit assemblies that can be assembled offline and then mounted on the engine model as a set. Examples of such tasks are the programming of the automatic transmission, assembly of the transmission oil cooler, or assembly of the oxygen sensor to a bracket. We found 100 offline tasks in total and created two supermarket stations with one worker each can assemble the kits and store them into bins along the production line.

Three different preassemblies have been assigned to two supermarkets. Those are the compressor kit, an oil cooler kit, and a filter kit. The reduction in tasks done online resulted in a decrease in the total inventory on the production line, as well. Supermarkets do not necessarily follow the takt time requirements. The kits, on the other hand, can vary from one engine model to another based on the number of components to assemble in the kit or the location to where the part will be assembled. To decide the location of the supermarkets, we studied the tasks precedence for each kit. The physical location along the layout will be determined after the line balancing phase. The size of the assembly kits and the engine demand is used to determine the number of supermarkets. Those two factors determine the needed capacity of the supermarkets and thus determining the number of the supermarket accordingly. The technique followed in this work is the two-bins supermarkets (Álvarez et al., 2008) where each assembly kit has two bins with a designated color. Once one bin is empty, it will be placed on the top of the bins rack to signal a pulling system where the worker needs to refill it.

Table 2. Assembly phases clusters for engines assembled on the assembly line.

| Phase Number | Phase                  | Immediate Predecessor |
|--------------|------------------------|-----------------------|
| 1            | Engine Pick            | None                  |
| 2            | Power Steering assembly| 1                     |
| 3            | Transmission Marriage  | 1                     |
| 4            | Transmission tightening left side | 3,6,9                  |
| 5            | Transmission tightening right side | 3,17                  |
| 6            | Transmission pick      | 10,11                 |
| 7            | Torque converter assembly | 3                    |
| 8            | Transfer case installation | None                 |
| 9            | Generator installation | 2,3,16                |
| 10           | Manifold installation  | None                  |
| 11           | Manifold tightening    | 10                    |
| 12           | Front differential installation | None              |
| 13           | Front drive shaft assembly installation | 4,9                 |
| 14           | Engine transfer from first to second zone | 3,4,5,6,8             |
| 15           | A/C Compressor installation | None               |
| 16           | Engine support bracket | 15                    |
| 17           | Transmission harness   | 6,10                  |
| 18           | Temp sensor, O₂ sensor routing | 4,9,10,17           |
| 19           | Oil cooler line install| 10                    |
| 20           | Harness routing and programming | 3                  |

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3.2.3. **Step 3: Task Mutuality Index (TMI)**

To simplify the design of the engine assembly lines, we developed a TMI by examining the work content to each engine model. This index assists in the analysis of the production line balancing before developing the optimization model. Often, the decomposition approach has been utilized in the early stage of a product design that consists of multiple systems of subcomponents (Pimmler & Eppinger, 1994; Siddique et al., 1998). This method is beneficial since it describes the general overall design interaction requirements even before the design of each subcomponent is completed. The work in this paper is using the design decomposition principles to the work content, that is assembly tasks, instead of the parts of the engine.

In this approach, the work content of each assembly station is the aim of the design. While the subcomponents are clusters of tasks that can be done sequentially on one station for each engine model. TMI is used to evaluate the similarities between the engine models based on the work content. We developed this index to simplify the number of engine models when performing the line balancing algorithm. It can also be evaluated based on time content (the total amount of time required to assemble the engine model) even if the task content is different.

We used the TMI to regroup the product into families; this approach is followed to enable achieving the goals of just-in-time (JIT) philosophy (Uddin & Lastra, 2011; Venkataramanaiah, 2008), it is similar to the approach used in cell manufacturing to allocate the machines over cells based on jobs commonality. The TMI deals with tasks and engines only. The first step is to create a matrix for all engines and tasks performed on the assembly line excluding the tasks of the supermarket. The following step computes engines pairwise similarity using TMI in Equation (2).

\[
TM_{ij} = \frac{K_{ij}}{K_{ii} + K_{jj}}
\]

where,
- \(TM_{ij}\) - Task commonality index between engines \(i\) and \(j\)
- \(K_{ij}\) - The number of tasks done for both engines \(i\) and \(j\)
- \(K_{jj}\) - The number of tasks done for one engine \((j)\) but not for both
- \(K_{ii}\) - The number of tasks done for one engine \((i)\) but not for both

Alternatively, the commonality among products can be calculated by investigating the commonality of the components of each product (Siddique et al., 1998). This approach will lead to comparable results of the task commonality index developed in this work since the components similarity will result in the similarity of variation of needed assembly tasks. However, the component-based approach relies on investigating the anatomy of each product and that may lead to more time and effort requirements to generate the product groups. The resulting TMI for all engine models is a square \(52 \times 52\) matrix with diagonal cells of ones. Upper and lower entry for every two engines is interchangeable.

3.2.4. **Step 4: products groups clustering**

The developed TMI provides information about the mutuality of tasks between two pair of engines. To establish engine groups based on the TMI, we developed a taxonomy
clustering algorithm. Clustering algorithms have been applied to cell manufacturing (Carrie, 1973; Gonalves & Resende, 2004; Srinivasan, 1994; Venkataramanaiah, 2008) to minimize the traveling distance between cells and cluster similar machines in the same cell. However, in this work the groups are a cluster of engines that possess the optimized highest TMI. As a result, minimal changes in task content will exist in each cluster, and this will lead to minimal changes in tooling and station setup. For engine products, this will also lead to standardizing the side of work for each group, since each group will be either right side drive or left side drive.

The grouping algorithm does not need a prior determination of the group’s numbers (Carrie, 1973). In this work, we developed a numerical taxonomy clustering algorithm for the study of similarities between engines based on the assembly task content. The mathematical analysis is based on one quantitative attribute that is the TMI value for each pair of engines.

For this analysis, we applied k-means clustering algorithm (Alsabti, Ranka, & Singh, 1997; Likas, Vlassis, & Verbeek, 2003; Xu & Wunsch, 2005), with an initial number of nine clusters and a single distance attribute expressed using the TMI. Since there is only one attribute, there is no need to use a weighting factor. The only adjustment for the TMI matrix is to express the mutuality of tasks content between engine models in a variable similar to a measured distance between two items. This modification is necessary because of the k-means clustering algorithms groups items is based on the minimum distance or ‘closeness’ to each other. Hence, we developed the closeness measure $DM_{ij}$ parameter matrix between engine models to perform the clustering algorithm. Equation (3) calculates the $DM_{ij}$ for each pair of engines. Table 3 lists examples of $DM_{ij}$ values for some engines.

$$DM_{ij} = 1 - \max(TM_{ij}, TM_{ji})$$

where,

- $DM_{ij}$ - The closeness measure between engines $i$ and $j$
- $TM_{ij}$ - The task mutuality index between engines $i$ and $j$
- $TM_{ji}$ - The task mutuality index between engines $j$ and $i$

There are nine resulting engines groups. Table 4 lists the number of engines in each group and the resulting time difference between the total time content of assembly tasks in minutes. The engine, in group one, with highest total assembly time requires 30.81 minutes to be assembled. The lowest overall assembly time in the same group needs 27.10 minutes. The similarity was calculated for the group to indicate the shared

Table 3. Example of generated $DM_{ij}$ matrix for engines based on TMI. !.

|       | KXC1 | KXC2 | KXC3 | KXC4 | KXC5 | KXC6 | KYC1 | KYC2 | KYC3 | KYC4 |
|-------|------|------|------|------|------|------|------|------|------|------|
| KXC1  | 1    | 0.85 | 0.72 | 0.9  | 0.4  | 0.3  | 0.2  | 0.25 | 0.3  | 0.25 |
| KXC2  | 1    | 0.8  | 0.82 | 0.4  | 0.3  | 0.2  | 0.25 | 0.3  | 0.25 |     |
| KXC3  | 1    | 0.7  | 0.4  | 0.3  | 0.3  | 0.35 | 0.35 |     | 0.3  | 0.35 |
| KXC4  | 1    | 0.4  | 0.3  | 0.35 | 0.4  | 0.45 | 0.45 |     | 0.45 |     |
| KXC5  | 1    | 0.95 | 0.4  | 0.4  | 0.45 | 0.45 |     |     |     |     |
| KXC6  | 1    | 0.4  | 0.4  | 0.45 | 0.45 |     |     |     |     |     |
| KYC1  | 1    | 0.98 | 0.95 | 0.9  |     |     |     |     |     |     |
| KYC2  | 1    | 0.9  | 0.87 |     |     |     |     |     |     |     |
| KYC3  | 1    | 0.8  |     |     |     |     |     |     |     |     |
| KYC4  | 1    |     |     |     |     |     |     |     |     |     |
tasks for all engines in the same group. All engines in group one share 0.86 of tasks. However, some engine pairs in the same group can have more than 0.86.

3.2.5. Step 5: considering demand forecast in products grouping

We further investigated the resulting nine engine clusters concerning demand forecast for the coming three months. Table 4 lists the demand forecast percentages for each engine group for the coming three months. Only five engine groups are dominant on the assembly line and their work content will be regularly performed compared to the rest.

We perform an investigation for the work content with the insight demand. Based on the developed TMI in this work, the engines in the low-demand groups, those are G1, G3, G6, and G9 have tasks that are performed on the left side of the engine and are not shared with any other engine groups. The nature of those tasks demands to spread them over stations due to the sequencing order with other main tasks.

This concept defines special stations that come and go based on the demand with assigned floater workers who are not assigned to a fixed station. Their tasks are changing dynamically as the type of engine changes. The floater job is to perform the special left side tasks on the engine on each station. This requires the worker to physically move with the low demand engine from one station to another. This will reduce the fluctuation in takt time due to increased tasks for low-demand engines and eliminate bottlenecks. In addition, specifying a worker whose job to handle special left-side tasks will improve the learning curve of the workers. The concept we developed created two routes for the same engine layout. These two routes differ in terms of the side of the work (i.e. left versus right sides of the engine) and the need for a floater worker. It should be noticed that machinery wise all required machinery for the floating routes are portable and can be moved easily from one station to another.

3.2.6. Step 6: production leveling (Heijunka)

To add more stability and predictability to the line redesign, production leveling is necessary to meet the required customer demand listed in Table 4. The presented work includes performing production leveling (Heijunka) to the engine groups. For every 100 engines produced on the assembly line, including an approximation of fractioned percentages, the resulted production leveling is listed in Table 5. Engine Groups 4 and 8 have the highest demand and the highest priorities on the production line. The rest of the engine

| Group | No. of Engines | Time Differences (min) | Similarity | % of Total Demand for Coming Three Months |
|-------|----------------|------------------------|------------|------------------------------------------|
| 1     | 6              | 3.71                   | 0.86       | 0.05%                                    |
| 2     | 12             | 1.44                   | 0.76       | 7.36%                                    |
| 3     | 13             | 5.93                   | 0.76       | 0.16%                                    |
| 4     | 9              | 7.35                   | 0.74       | 38.61%                                   |
| 5     | 3              | 0.19                   | 0.98       | 8.04%                                    |
| 6     | 2              | 0.07                   | 0.99       | 0.00%                                    |
| 7     | 3              | 0.07                   | 0.98       | 9.38%                                    |
| 8     | 3              | 0.16                   | 0.96       | 36.38%                                   |
| 9     | 1              | NA                     | NA         | 0.02%                                    |

Table 4. Engines clusters results after applying the K means clustering algorithm.
groups, low runners designated with the red route, are assigned 1 out of each 100 produced engines. This means the red route assembly worker will be working on the production line once every 100 engine, this will enable him/her to work on the supermarket and be a floater worker that moves along with the red route engine along the production line.

3.3. Phase-II: assembly line balancing

The presented work is divided into two phases that is the core and the merit of this work the first phase is applying lean manufacturing principles to reduce waste and improve the overall assembly line efficiency. The second is the line balancing using optimization modeling. The second phase of assembly line designs includes applying optimization models to achieve the required takt time for each station. The previous phase of lean manufacturing reduced the computational and modeling needs by reducing the number of engines to nine groups based on work content mutuality thus minimizing the work content that needs to be allocated by the optimization model. In addition, the previous phase reduced the waste, time-wise, that was spent on offline tasks.

3.3.1. Model explanation

Most of the assembly line problems use decomposition algorithms, multistage algorithms, genetic algorithms, and several other techniques as summarized by Pearce (2015). Based on the tuple-notation \((a|\beta|y)\), defined by Boysen et al. (2007), we used a model that is classified as \(mix|\{o, o, div\}|m\). This means that the stations are in series, asynchronous works piece movement between stations, line processes mixed models, and with an objective to minimize the number of stations for the specified takt time. In the problem representation \(\beta = \{o, o, div\}\), implies that the model is a paced line with average cycle time at each station and the cycle times diverge between stations and/or models (Boysen et al., 2007).

The assembly line we consider has 27 stations and 500 tasks that can manufacture 52 different models. Proplanner\texttrademark line balancing software can balance the mixed model assembly line to minimize the number of stations when given the desired cycle-time (takt) as an input. The data library includes the constraints for the line balancing problem. The input details required for the model are classified into the station, model, and task details. The station details include the list of all stations and the order in which it is arranged. The model details include the different product models and their forecasted demand. The tasks details include the different tasks, their processing time, precedence relationships among various tasks, work zone (left, center, or right), and the different models that need these tasks. Constraints related to task assignments to stations by the following precedence is part of the module. The number of constraints is proportional to the number of stations, tasks, and models since decision variables assign tasks associated with a model to a station based

| Engine Group | \(G_4\) | \(G_8\) | \(G_5\) | \(G_7\) | \(G_2\) | \(G_{Red}\) |
|--------------|--------|--------|--------|--------|--------|-----------|
| Number of Engines | 39     | 37     | 9      | 8      | 7      | 1         |
on their precedence relationship. The lean approach reduced the number of stations from 27 to 21. The tasks associated with each model follows the model-task mapping matrix as shown in Table 6.

In the algorithm, we used a weighted average balance, which considers the use of weighted times for the tasks based on the demand percentages. This is confirming to the assigned engine models of high runner and low runner ones. The allocation of weighted times based on the demand percentage shifts the line balancing focus towards engine groups that will be dominant.

4. Results and discussion

The results of takt time after the line redesign showed a significant reduction in takt time per station. This can be illustrated in plotting the takt time before and after the application of the proposed hybrid approach in this work, see Figure 3. The results indicate a reduction of the maximum takt time from 1.76 minutes to 1 min. The line is balanced at a takt time per station ranging from 0.16 to 1.0 minutes. We present a brief comparison between the takt times before and after implementing a weighted average algorithm for ALB problem shown in Figure 4. The box plot explains the variability of takt time values. The spread of takt times for the stations before and after ALB algorithm indicates that the takt time has not only reduced but also have an equal distribution of time in all stations.

Figure 5 provides a comparison of the number of tasks that are assigned before and after the proposed approach in this work. The results show that the variability in stations’ takt time is reduced after the application of the lean manufacturing principles and the ALB algorithm.

The resulted layout design of the assembly line is shown in Figure 6. We proposed a main black route assigned for engine models groups that have high demand or high runners. The red route is assigned to engine models groups with low demand. A red route worker is tasked with performing left side tasks on the engine model while the black route worker is performing the main tasks on the side. The red route worker will move from one station to another with the engine model to perform the special tasks in the required sequence. It should be noted that based on the current demand forecast the red route will be active once every 100 engines sequence based on the Heijnuka analysis shown in step 6.

The overall performance of the assembly redesign approach can be quantitatively assessed using the number of stations, number of workers, number of supermarkets, final takt time, and number of engine models required to be modeled in the ALB. Table 0 lists the values of the performance measuring metrics for the before and after applying

| Tasks | Time (Minutes) | Models |
|-------|---------------|--------|
|       | M1 | M2 | M3 | M4 | M5 | M6 |
| Task 1 | 0.942 | 1  | 1  | 1  |     |     |
| Task 2 | 0.336 | 1  | 1  | 1  | 1   |     |
| Task 3 | 0.336 | 1  | 1  | 1  | 1   |     |
| Task 4 | 0.545 |     | 1  | 1  | 1   |     |
| Task 5 | 0.545 | 1  | 1  | 1  |     |     |
| Task 6 | 0.336 |     | 1  | 1  | 1   |     |
| Task 7 | 0.153 | 1  | 1  | 1  | 1   | 1   |
Figure 3. Box-plot with range for the takt times.

Figure 4. Comparison of takt time before and after applying the proposed approach for assembly line redesign.

Figure 5. Number of tasks per stations before and after applying the proposed approach for assembly line redesign.
the proposed approach. In addition, to the listed improvements in Table 7. It can be seen from the number of stations that the layout of the assembly line is reduced by eliminating the third zone. It should be noted that the zone still can have added stations in the future if a redesign suggests so.

5. Conclusion

The adaptation of lean manufacturing principles in MALB can reduce computational complexity and improve line balancing. The authors proposed a hybrid approach that includes a reduction of waste in terms of task content. The work investigated offline and online tasks to

| Parameters          | Before Redesigning | After Redesigning |
|---------------------|--------------------|-------------------|
| No. of stations     | 27                 | 21                |
| No. of workers      | 27 (100% utilization) | 21 (100% utilization) |
|                     | (Black main route)  | (Black main route) |
|                     | 3 (100% utilization) | 3 (100% utilization) |
|                     | (Red router floater workers and supermarkets) | (Red router floater workers and supermarkets) |
| No. of supermarkets | 0                  | 2                 |
| Takt time per station | 10–106 seconds | 60 seconds or less |
|                     | (unbalanced)       | (balanced)        |
| No. of engines models | 22                | 52                |
create supermarkets, and to study the left and right side of work to enable floater workers. The approach continues by creating product families based on task mutuality and K means clustering algorithm followed by utilizing ALB algorithm. In the case of the presented AE assembly line, the different engine models can fit into groups, which will facilitate dealing with future new models that can be categorized under one of the existing groups. As a result, the assembly line redesign can have more stability and fewer future needed changes. The proposed approach proved feasibility with limited layout changes allowed and reduced the number of assembly stations from 27 to 21 and total workers from 27 to 23. The effectiveness of the proposed approach relies on establishing the MTS data and the demand for product models that will be dominant on the assembly line. This information enabled applying the lean manufacturing principles for the work content and effectively applying an ALB algorithm with fewer constraints to meet and less molding complexity.

Future research directions will focus on investigating the proposed approach effectiveness in mixed model’s assembly lines with versatile products nature. Most importantly, the effectiveness of the clustering algorithm to generate feasible product groups that can lead to an enhanced assembly line optimization problem with less computational complexity and reduced analysis time. This is of importance as more assembly lines are required to meet customized products and move towards construction of a general process flow platform that manufactures versatile products.

The evaluation of the developed method for assembly line with already existing approaches cannot be done generically. Researchers developed metrics to be able to evaluate the efficiency of a line balancing approach. Metrics such as balance delay and smoothness index (Chao & Sun, 2016) are used. Mainly the evaluation intended to measure the solution difficulty (Driscoll & Thilakawardana, 2001), namely measures such as order strength (Driscoll & Thilakawardana, 2001), flexibility ratio (Bukchin et al., 2002), west ratio (Bukchin et al., 2002), and time interval (Baykasoğlu & Özbakır, 2015) are used. Future work direction will also focus on evaluating the proposed approach along with other available approaches using assembly line metrics.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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