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Application of Line Balancing Heuristics for Achieving an Effective Layout: A Case Study

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A B S T R A C T

This project is a case study conducted in a manufacturing company aiming at improving its productivity using line balancing techniques. Waste reduction, especially the time waste, is an important factor to shrink the manufacturing cost. The main purpose of this project is to suggest a better line balancing approach with an aim of reducing the idle time, work station number, and manpower requirement while improving the efficiency to meet the target production in the apparel manufacturing organization. For accomplishing the purpose, different line balancing methods named Largest Candidate Rule, Kilbridge & Wester method, and Ranked Positional Weight method carried out for analyzing the line efficiency, production rate, work station number, manpower requirement, and time utilization. Finally, an efficient and balanced line were proposed with respect to the auspicious outcome of the production area. Also, by using the line balancing techniques, a new sequence of work has been developed to arrange the work elements into the workstation. Some optimum layout has been proposed that has minimized the idle time and manpower requirement.

Keywords: Line balancing techniques, Idle time, Manpower requirement, Line efficiency, Auspicious outcome.

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1. Introduction

Line balancing means to allocate the work element equally in various workstations. Assembly line balancing is an important and challenging task for industrial engineers in today's mass production oriented company. The key problem facing while balancing an assembly or operation line is how to assign a set of task to specific workstations so that precedence relationship is satisfied and performance is optimized [1]. The production line is usually balanced for gaining a better layout that will ultimately increase the line efficiency. A balanced process is one where

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cycle time or task time in each stage is approximately equal. The revised layout is essential for any garment manufacturing company for assessing its effectiveness through the computer simulation [2]. Some Japanese manufacturing industries, such as automobiles, electronics, and machinery achieved high levels of international competitiveness in the 1980s through assembly line balancing [3]. So balancing the line is one of the preconditions for achieving a just in time manufacturing system.

Unequal workload in workstations of an assembly line in a garment factory will lead to higher increase of both Work-In-Progress (WIP) and waiting time. Thus both production cycle time and cost are increased. So, the industrial engineers are more concerned with the balance of the lines by appropriately assigning the tasks to workstations as equally as possible [4]. One of the main challenge concerning the development of an assembly line is to arrange the task to be performed. During the first forty years of the assembly line invention, only trial and errors were used to balance the line. But this was costly time consuming and that is why if the production manager was needed to develop a new system; he had to observe it in a computerized system that will involve visualizing production process and bottleneck stations [5]. The line balancing has been an optimization problem of significant industrial importance. The first article was published by Salveson [25] where he used the integer programming model to solve the problem [6].

While talking about the garment industries, most garment of them follow the typical flow of production. Product parts are assembled through a sub-assembly process until garment components are gathered into a finished garment. The entire process includes a set of workstations where the specific task is carried out in a restricted sequence with significant number of employees and thousands of bundles of sub-assemblies producing the different styles simultaneously. The assembly process of components along with the sewing process is regarded as the most labor intensive part of garment manufacturing [7]. Task time which is also called processing time is the necessary time to perform a task by any specific equipment. The same or different resource or machine might be required to produce the tasks. The traditional way to complete the whole task is using the precedence diagram [8]. Assembly Line Balancing Problem (ALBP) has been an active field of research over the past decades due to its relevancy to diversified industries such as garment, footwear, and electronics [9].

The goal of line balancing technique in any kind of industries including garment industries is to minimize the idle time as much as possible [10]. The Largest Candidate Rule, Kilbridge and Wester (column), and Ranked Positional Weights (RPW) are different heuristic methods commonly used to arrange and distribute the work elements according to their task time in different workstations in the system. Each of those methods provides a different type of workstations layout [11]. The cycle time of an assembly line is predetermined by a desired production rate in a way that the desired amount of end product is produced within a certain time period [26]. In this regard, one of the main issue is how to arrange the tasks in production line to be performed. An effective way to achieve this goal is to balance the assembly lines and work cells [12].

Although the problem is easy to formulate, the enumeration of the feasible task sequences for finding out the minimum number of stations requires an enormous effort. The minimum number of stations subjects to the following constraints are: (a) All tasks have to be performed, (b) the work content in any station cannot exceed the cycle time, and (c) precedence relationships are satisfied [13].

The implementation of different heuristic assembly line balancing methods in the apparel industry and their comparison was thoroughly discussed in [14]. Although there are quite a lot of heuristic methods, some basic ones taken from literature can be listed as follows: Ranked positional weight method (Helgeson-Birnie), enumeration method (Jackson), Hoffman method, Moddie-Young method, COMSOAL method (Arcus), dynamic programming method, Kilbridge and Wester method, candidate matrix method (Salveson), probabilistic assembly line balancing method (Elsayed-Boueher), grouping method (Tonge), shortest path method (Klein-Gutjahr), Raouf-Tsui-Elsayed method, related activity method (Agrawal), and basic heuristic method [14]. Assembly lines balancing configurations for single and multiple products are divided by three types, single-model, mixed-model, and multi-model. Single-model assembles only one product, and mixed-model assembles multiple products, whereas a multi-model produces a sequence of batches with intermediate setup operations [15]. This article focuses on single model line balancing problem with real application in garment manufacturing industry.

Line balancing enables the researcher to gain a critical insight into the performance of a manufacturing company. Sewing department involves manual labor, the process often resulted in a high cycle time and low productivity. Sewing department contribute a lot of problem in garment manufacturing company. There are lots of different operations done manually and the sewing operations need high skill as well as quality work [16]. Since sewing process is related to manual labor, without material costs, the cost structure of the sewing process is also important. Therefore, this process is of critical importance and needs to be planned more carefully [17]. Each operator is needed to carry workloads properly thus a synchronous flow is gained throughout the entire production line [18].

A production line in a production system processes the raw materials and then converts them into a finished product after a set of value added activities [19]. The main process of converting raw materials into a garment is common. But, according to the experience of the institute, the types of problems faced by garment factories are dependent on the scale of the manpower in factories [20]. Sharing a small elemental job of work between several people is called division of labor. Each and every step in the assembly of product should be observed carefully and allocation of work elements to station in a balanced way over the available workstations [21]. A synchronous flow of operations among different workstations is achieved through appropriate division of labor.

In garment industry, we deal with using the manual assembly lines. In the manual assembly line balancing problems we get a good result when (1) largest candidate rule, (2) Kilbridge and Wester method, and (3) ranked positional weights method are used because:

- These methods are heuristic, meaning they are based on common sense and experimentation rather than mathematical optimization.
- The total work required to assemble the product can be divided into small work elements.
- It is technologically impossible or economically infeasible to automate the assembly operations.

2. Problem Statement

The research study area was the sewing section which is the most important department in the garment industry. Primary data was collected from the "trouser" production line. FCI (BD) LTD have two sewing floor. Sewing floor no.1 was selected as our case study area. Initially, it was observed that there work elements are not allocated to the workers in an effective way. We collected general sewing data from sewing line no.17 and then started trying to balance the line using line balancing heuristics. The purpose of this work was to propose a layout to change the traditional line. Numerous data regarding total work element, the time required for each individual work element, the individual work element production rate, the target production rate, and the total no of operator required to meet the demand were collected.

3. General Methodology

The whole process of study work was shortly explained by the following flowchart.

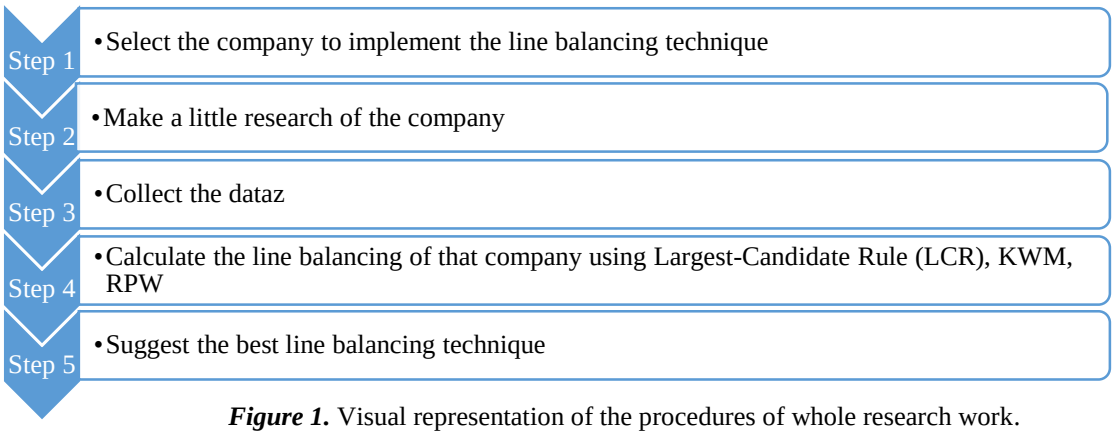

Figure 1. Visual representation of the procedures of whole research work.

3.1. Analysis Terms

The following terms were used during the project. The formulas were taken from different publications [6, 8, 10, 13, 14, 15, 17, 22, 23, 24].

Cycle Time= Bottleneck Station Time.

Idle Time = Cycle Time – Service Time.

Theoretical Manpower = $\frac{\text{Target per hour}}{\text{Process Capacity per hour}}$.

Theoretical Minimum No of Workstation Minimum Inte $\geq \frac{\text{Total Work Element Time}}{\text{Cycle Time}}$.

Line efficiency = $\frac{\text{Total Station Line Time}}{\text{Cycle time x no.of workstation}}$* 100%.

4. Data Analysis and Result

4.1. Current Factory Scenario

The current production situation of the observed industry area where the total work element time was 28.04 minute and the total manpower required was 66 (according to industry sector data). The following figure shows the precedence diagram of the current scenario of the observed area and it was drawn according the guidance followed by [13, 22, 23, 24].

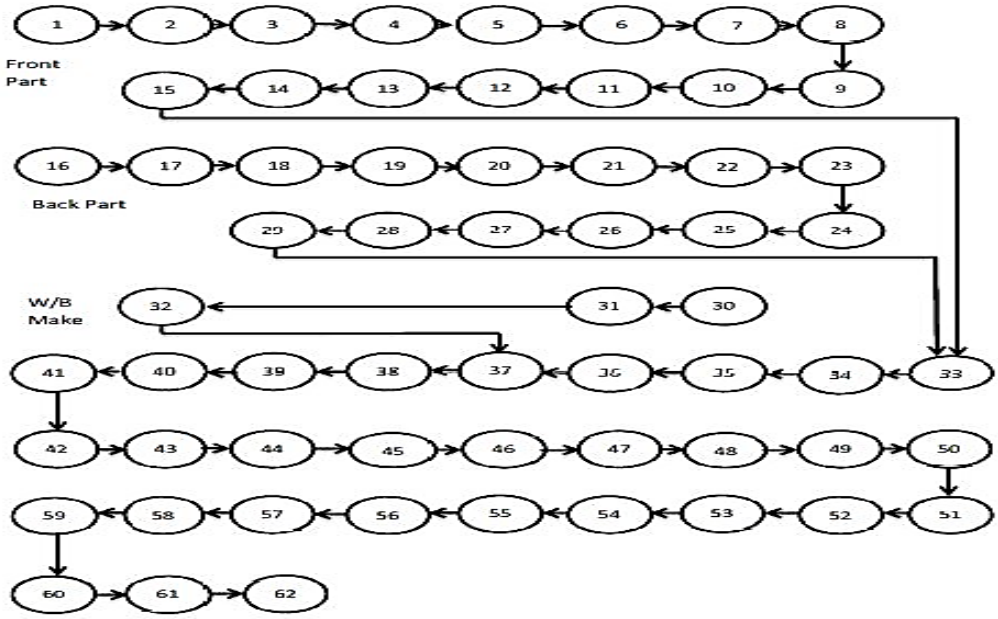

Figure 2. Precedence diagram of the process.

Here work element number 37 consuming most time so it was the bottleneck station in accordance with [13], [16] and [23] and the collected cycle time for that was 1.2 min.

The target output of the factory at 75% labor efficiency was 99 pieces per hour.

The current line balancing efficiency:

Line efficiency = $\frac{\text{Total Station Line Time}}{\text{Cycle time x no.of workstation}}$* 100% = $\frac{28.04}{1.2 \text{ x } 62}$* 100% = 37.69 %.

4.2. Using Largest Candidate Rule to Assign Work Element into Station

By listing all elements in descending order of work element value according to the procedure followed by [4, 6, 8, 10, 13, 14, 15, 22, 23]. Considering the highest cycle time 1.2, the minimum no of workstation can be determined by using the following formula followed by [13, 14, 22, 23, 24].

Theoretical Minimum No of Workstation = minimum Integer ≥ $\frac{\text{Total Work Element Time}}{\text{Cycle Time}}$ = 23 ≈ 24.

Line efficiency =$\frac{\text{Total Station Line Time}}{\text{Cycle time x no.of workstation}}$ * 100% = $\frac{28.04}{1.2 \text{ x } 30}$* 100%= 77.89%.

Assignment of work element according to largest candidate rule was shown in ***Figure 3*** and according to the guidance followed by [13, 22, 23, 24].

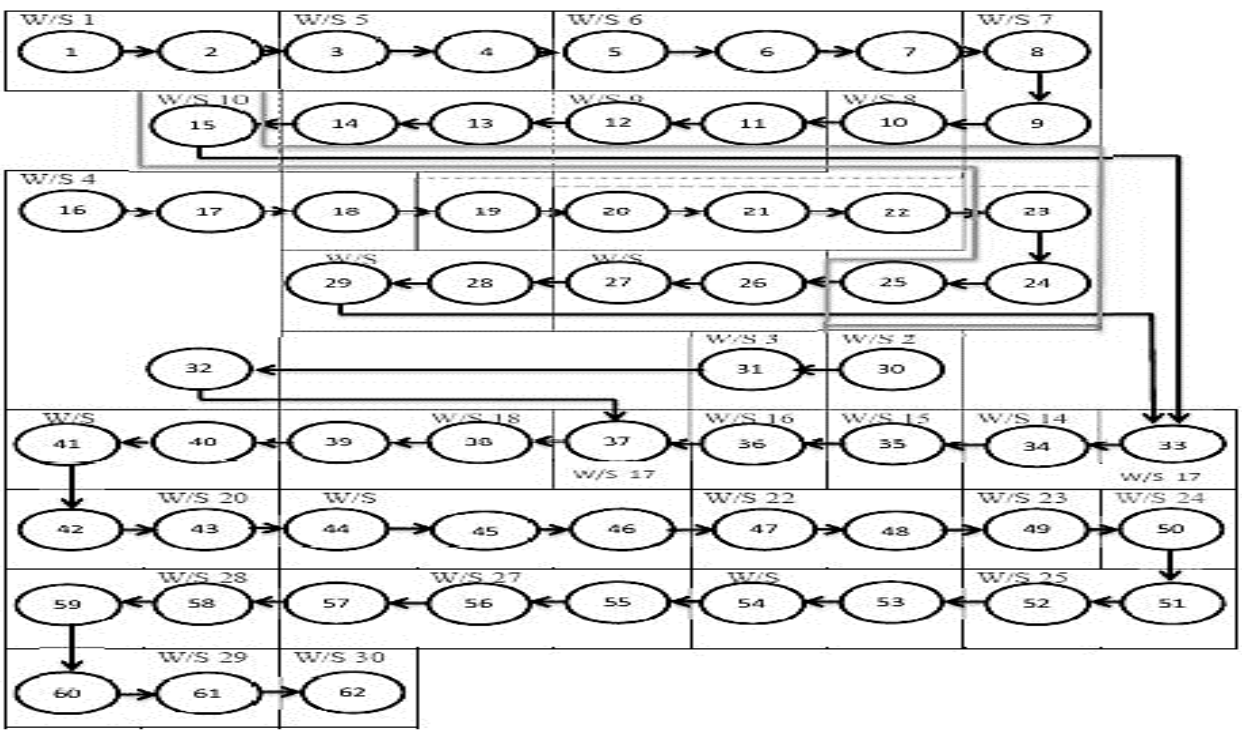

Figure 3. Assignment of work element according to largest candidate rule.

To meet the target production, the manpower assignment in different stations is necessary. Here in this method, the total manpower required was 57.

4.3. Using Kilbridge and Wester Method to Assign Work Elements into Station

To Assign work element into various work station in KWM, arrangement of work elements according to column was needed that could be obtained from previous figure. While assigning the work elements, it was considered that the assignment does not violate the precedence constraints and cycle time.

Now work elements could be assigned to work stations according to KWM method by following the guidance from [6, 8, 10, 13, 14, 15, 22, 23]. The line efficiency is obtained by using the following formula followed by [6, 8, 10, 13, 14, 15, 17, 22, 23, 24].

$$\text{Line efficiency} = \frac{\text{Total Station Line Time}}{\text{Cycle time x no.of workstation}} * 100\% = \frac{28.04}{1.2 \text{ x } 29} * 100 = 80.57\%.$$

Assignment of work element according to Kilbridge & Wester method was shown in ***Figure 4*** according to the guidance from [13, 22, 23, 24]. In ***Figure 4*** same colour within a box indicates the same workstation. To meet the target production, manpower assignment in different work stations was necessary. Here in KWM, total 54 manpower was needed to meet the target production rate.

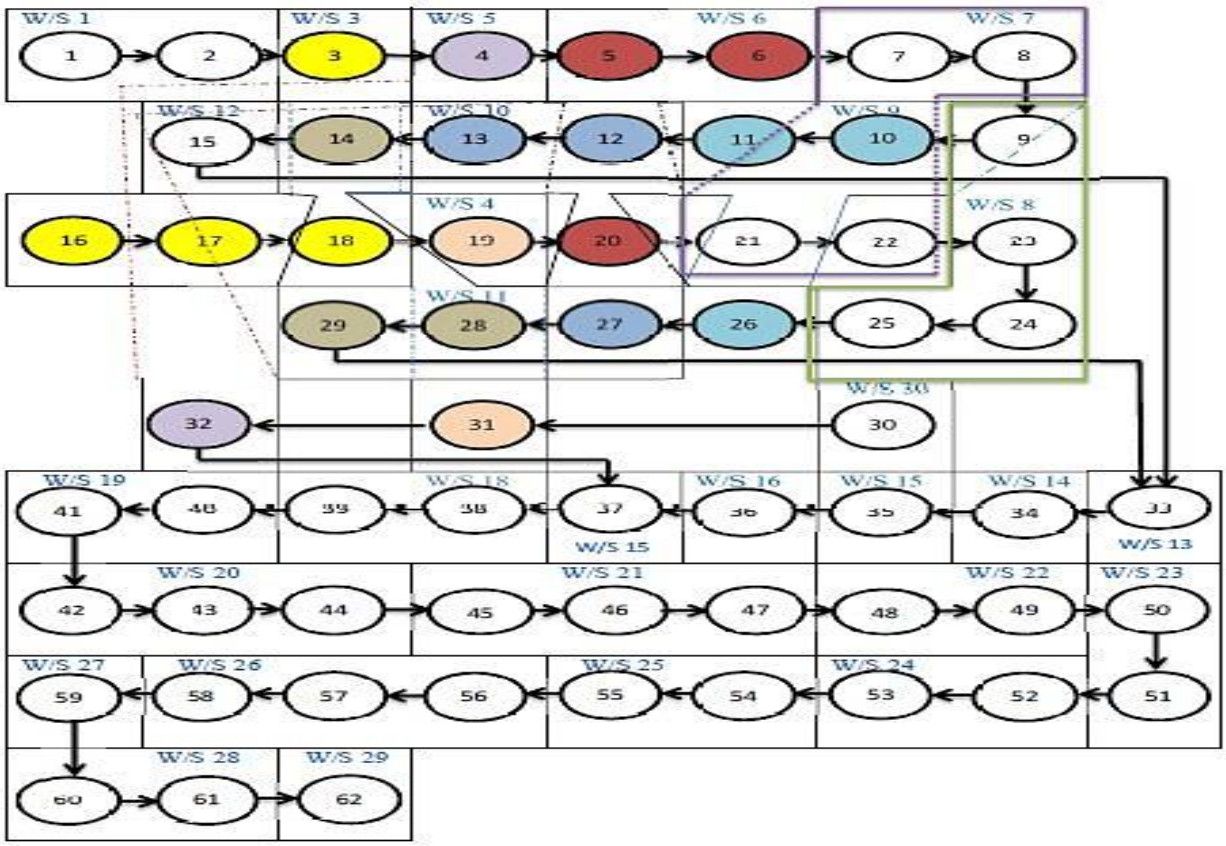

Figure 4. Assignment of work element according to Kilbridge & Wester method.

4.4. Using Ranked Positional Weight Method to Assign Work Element into Station

For assigning work elements in different work stations in RPW method, it was needed first to collect different RPW of each work element from the observed area and then listing the elements in order of their RPW and largest RPW at the top of the list. The ***Figure 5*** was drawn according the guidance obtained from [13, 22, 23] which shows the RPW of each element that were collected from the observed sector and the arrangement of the work elements according to largest RPW value. While assigning the work elements, it was considered that the assignment does not violate the precedence constraints and cycle time.

After getting the result it was possible to assign the work elements into work stations according to RPW method following the guidance obtained from [6, 8, 10, 13, 14, 15, 22, 23]. Now the line efficiency could be obtained by using the following formula obtained through [6, 8, 10, 13, 14, 15, 17, 22, 23, 24]. Line efficiency = $\frac{\text{Total Station Line Time}}{\text{Cycle time x no.of workstation}}$* 100% = $\frac{28.04}{1.2 \text{ x } 28}$* 100= 83.45%. Assignment of work elements according to RPW method was shown in ***Figure 5*** according to the outcome obtained and by following the guidance of [13, 22, 23, 24]. In the following figure, same colour work elements within a box indicates that those are assigned to the same workstation. To meet the target production, the manpower assignment in different work stations was necessary. The manpower distribution in RPW method which was drawn through the guidance was obtained from [14, 15, 22, 23]. Here in RPW total 54 manpower was needed to meet the target production rate.

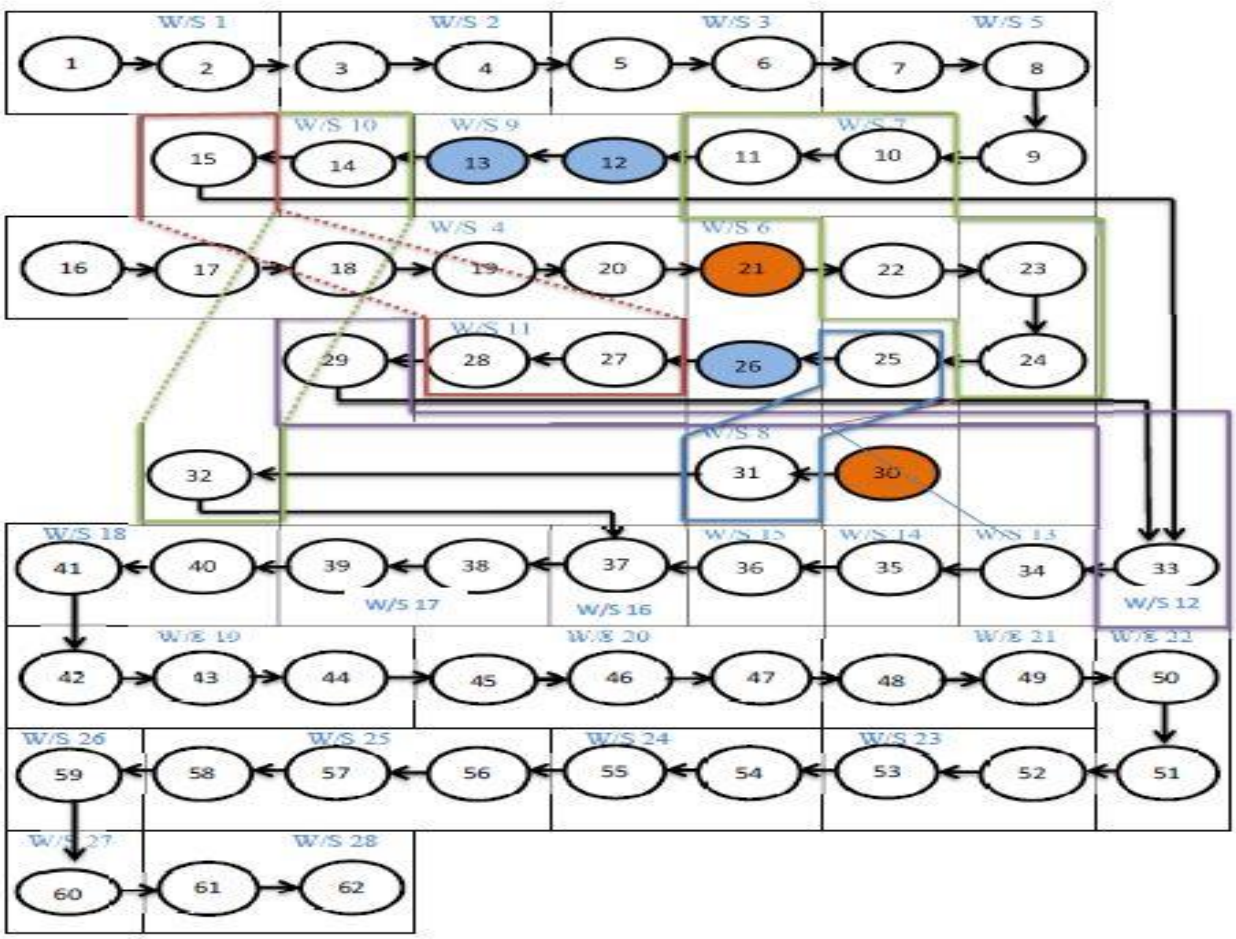

Figure 5. Assignment of work element according to RPW method.

5. Results and Findings

Here ***Figure 6*** graphically illustrates the service time and the idle time for the current line balancing technique.

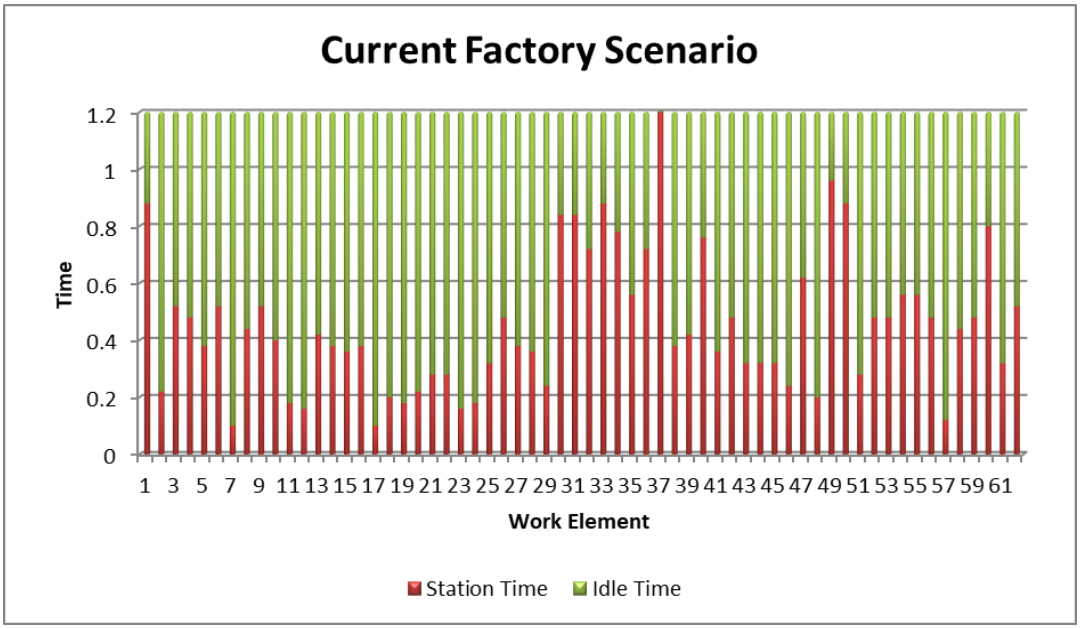

Figure 6. Service time and idle time of current line balancing technique.

Here ***Figure 7*** graphically illustrates the service time and the idle time for the LCR line balancing technique.

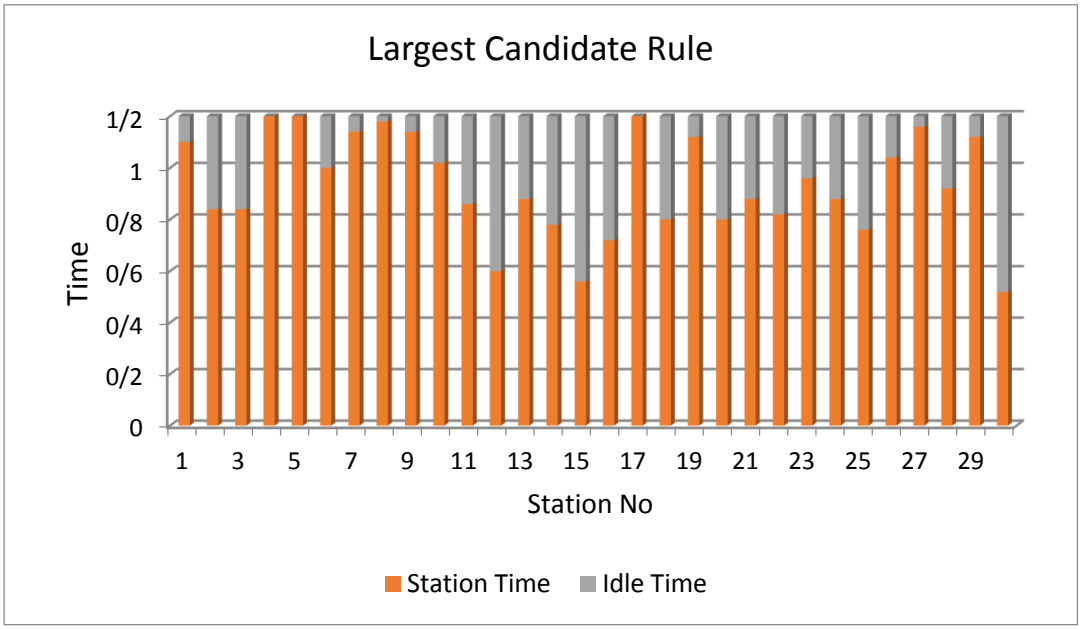

Figure 7. Service time and idle time of LCR.

Here ***Figure 8*** graphically illustrates the service time and the idle time for the KWM line balancing technique.

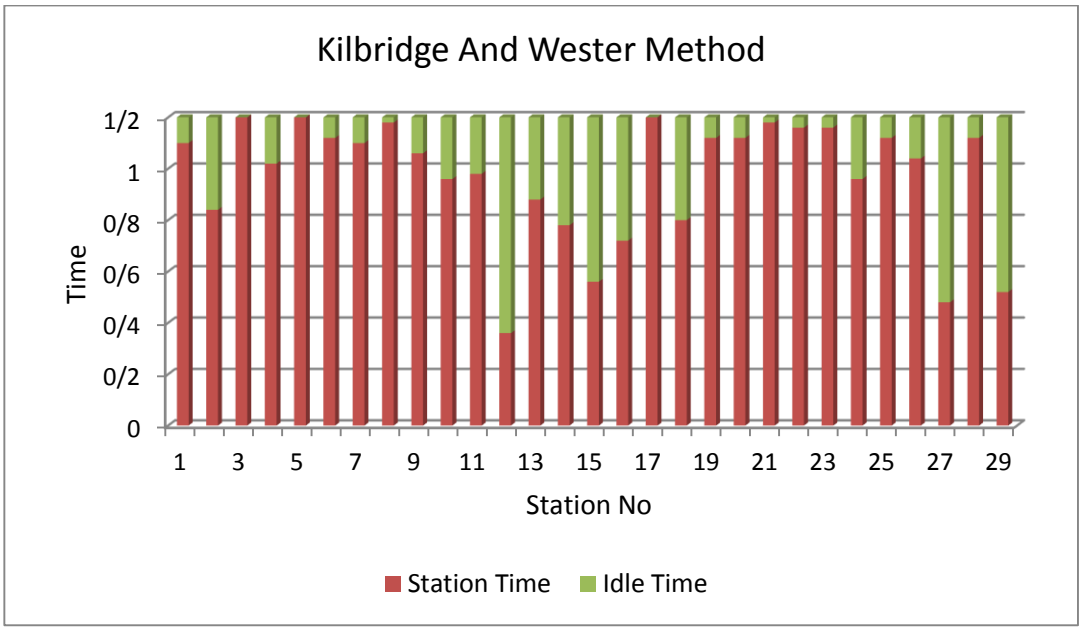

Figure 8. Service time and idle time of Kilbridge and Wester's Method (KWM).

Here ***Figure 9*** graphically illustrates the service time and the idle time for the RPW line balancing technique.

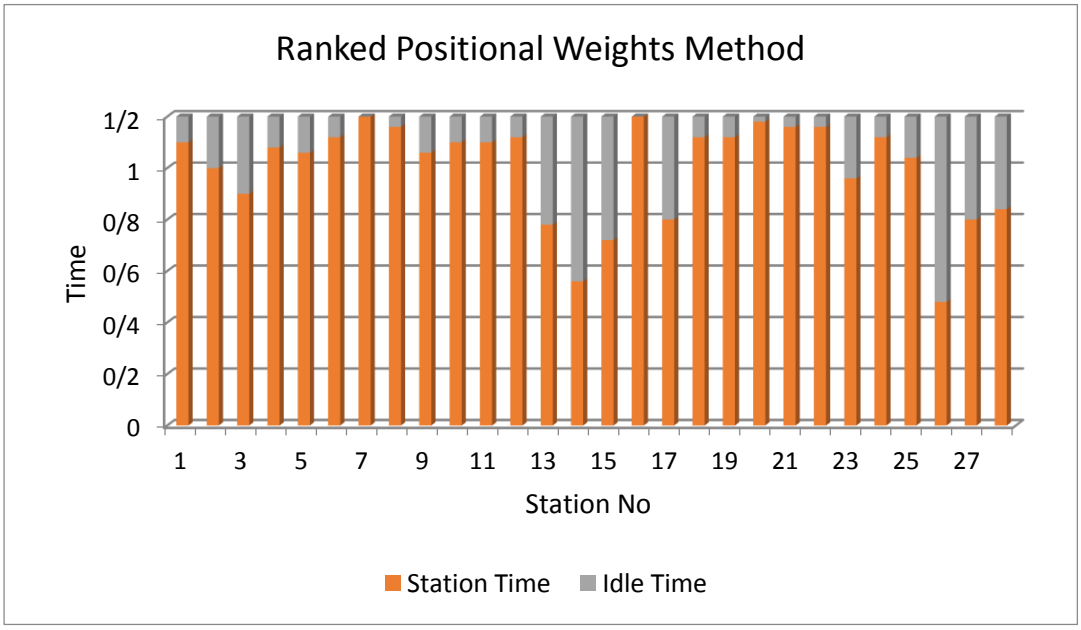

Figure 9. Service time and idle time of RPW**.**

6. Comparison among Different Line Balancing Techniques:

In this part, comparison among current technique and different line balancing techniques were carried out with respect to station number, line efficiency, manpower number, and idle time.

Comparison of station needed in different line balancing techniques are shown in ***Figure 10.***

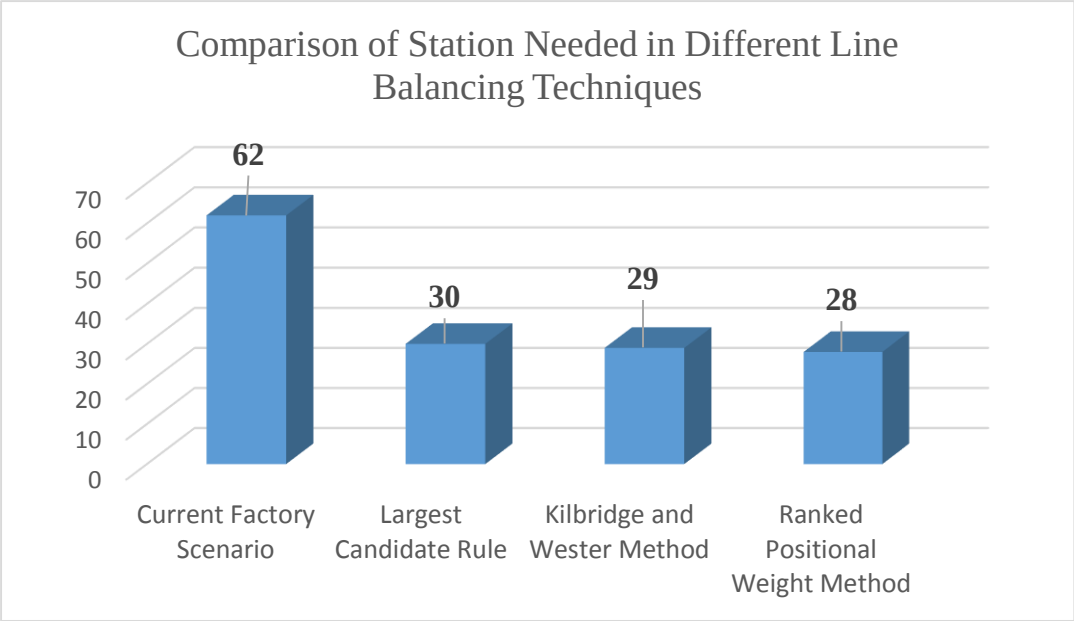

Figure 10. Comparison of station needed in different line balancing techniques.

Comparison of efficiency among different line balancing techniques are shown in ***Figure 11.***

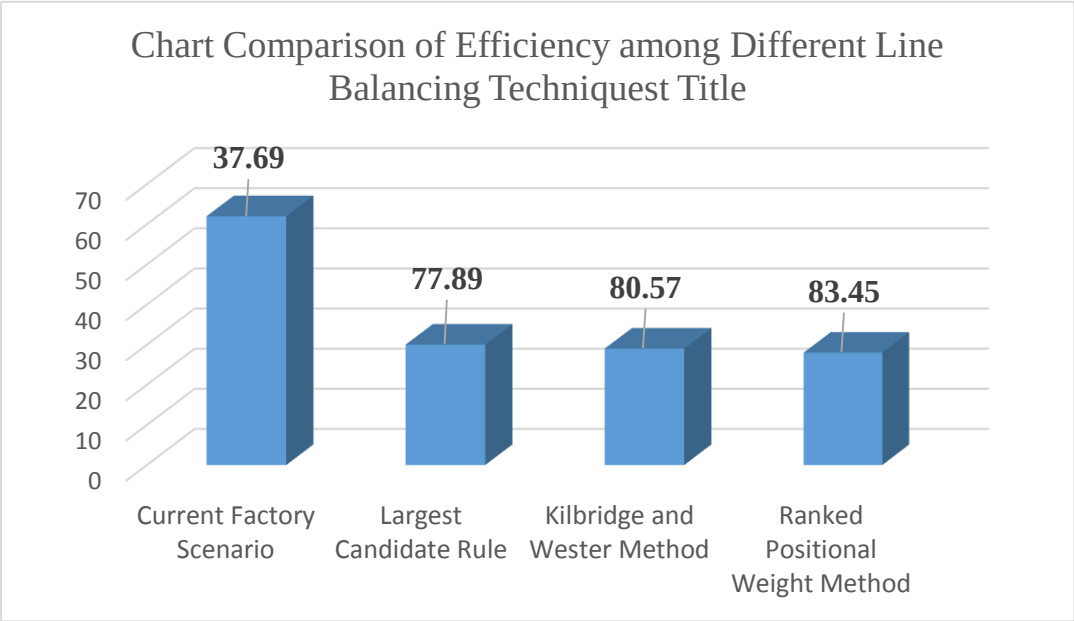

Figure 11. Comparison of efficiency among different line balancing techniques.

Comparison of manpower needed among different line balancing techniques are shown in ***Figure 12.***

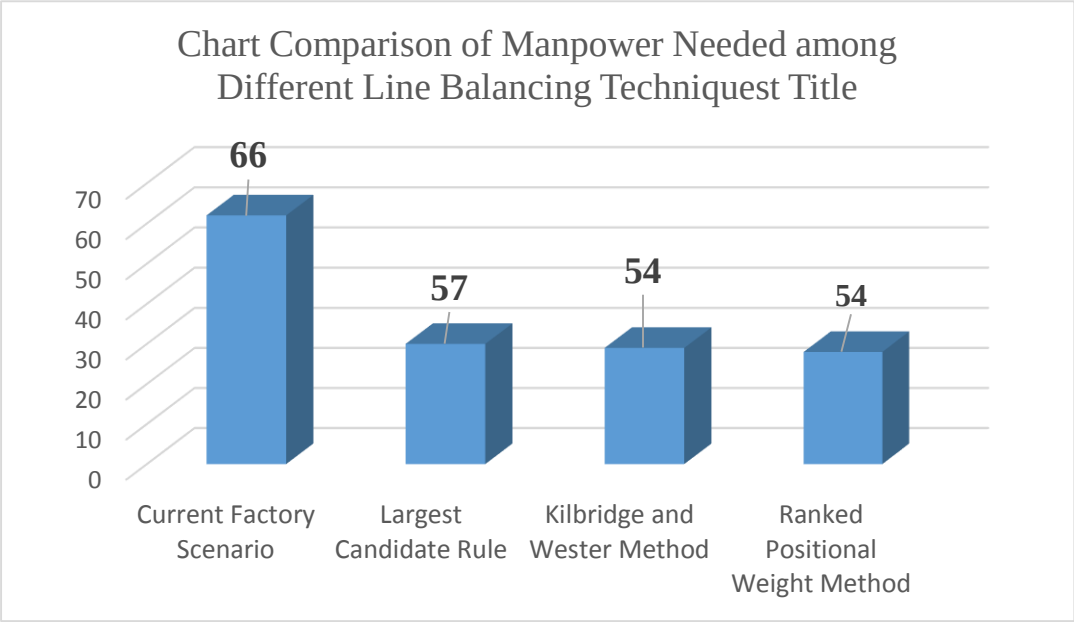

Figure 12. Comparison of manpower needed among different line balancing techniques.

Comparison of idle time at different stations in different techniques are shown in the ***Figure 13.***

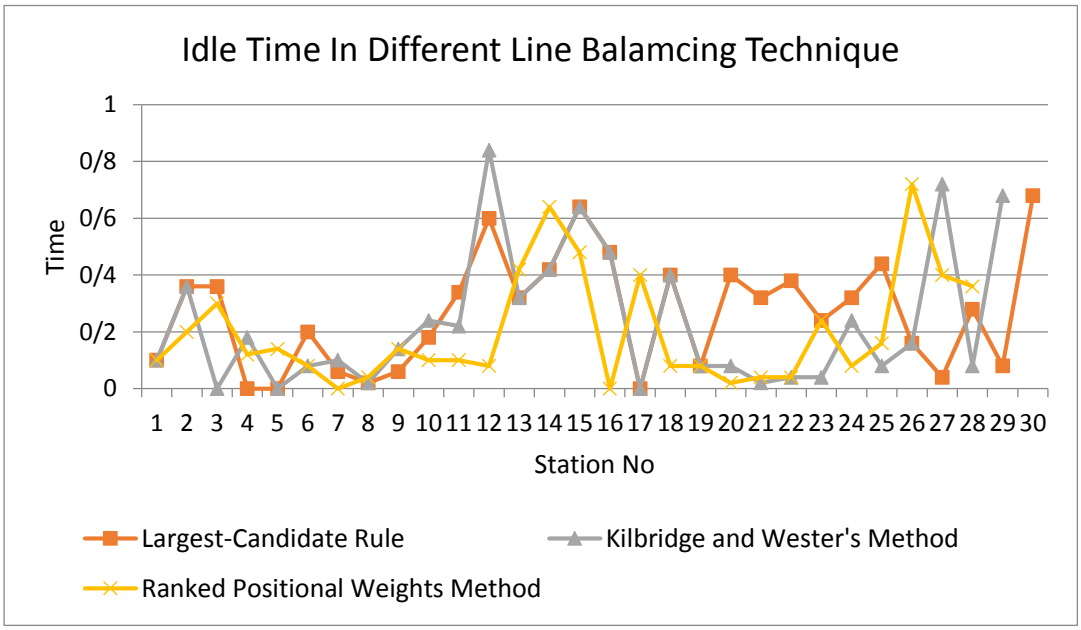

Figure 13. Comparison of idle time at different stations in different techniques.

After analyzing the ***Figures (10)-(13)***, it could be said that RPW method was comparatively better than other methods and current scenario in terms of better efficiency, less idle time, lower manpower requirement, and lower station number. For this reason, RPW line balancing technique could be suggested for the observed industry area for better efficiency, lower station number, lower manpower requirement, and less idle time.

7. Discussion

In the largest candidate rule method, the work elements are arranged in descending order according to their work element time values. Kilbridge and Wester Method is a heuristic procedure that selects work elements for assignment to stations according to their position in the precedence diagram. This solves one of the problems with the largest candidate rule in which an element may be selected because of a high work element time value ignoring its position in the precedence diagram. In general, the Kilbridge and Wester method provides a superior line balance solution. The three heuristics are far more superior than the present situation of the manufacturing process in terms of efficiency, man power, and number of workstation as three systems reduce the idle time (non-value added time) significantly. Among the three models, the RPW method gives the better result because the RPW takes into account both the work elements time value and its position in the precedence diagram. So elements are compiled into a list according to their RPW value. For that reason the rank positional weight method always have the better efficiency, lower number of workstations, and less man power. RPW method is highly recommended for improving overall efficiency of this project.

8. Conclusion and Findings

Applying the suggested workstation design (according to RPW method) will improve the productivity significantly. In the new proposed model, the productivity increases 990 pieces per day to 1000 pieces per day. Workstation needed 28 from 62 which also met the target production rate. Line balancing efficiency increased from 37.69% to 83.45%. To meet the target production, manpower reduced 54 from 62.

- The lowest number of station is found when we use the RPW method however it was very close to the number we found using other two methods.
- If we arranged our workstations in the RPW method we got the best efficiency. The efficiency of the other methods are not far behind.
- Same number of man power needed in Killbridge and Wester's method and RPW method 54.
- The other 3 process are far more efficient and well organized than the current methods. If we arrange or cluster the operations then we can reduce the idle time and bottleneck overall non value added times.

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