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# Productivity Improvement of Garments Industry by Implementing Line Balancing Algorithms—A Case Study

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## ABSTRACT

Nowadays, the apparel industry is highly competitive worldwide and requires the correct application of industrial engineering techniques such as time study and line balancing techniques for productivity improvement. Productivity improvement in the readymade garments industry is mostly dependent on lead time as well as the cost of production. This research aims to recommend an effective layout and line-balancing strategy so that downtime, process bottlenecks, the number of workstations, and the required number of personnel can be minimized to improve the efficiency of the production line. For this purpose, three different heuristics approaches named the Ranked Positional Weight (RPW) method, the Largest Candidate Rule (LCR), and the Kilbridge & Wester method are implemented for analyzing the production line. After the implementation of line balancing techniques, it was found that all three methods improved the line efficiency compared to the existing line efficiency. Among the three heuristics methods, the RPW method and LCR increased efficiency more compared to the Kilbridge and Wester method (KWM). By lowering the current 42 workstations to 23, the RPW method and LCR demonstrated an improvement in the line efficiency of the current hemming unit to 79.80% from 43.70%. The RPW approach or LCR will be effective in terms of efficiency in this particular situation. Finally, an efficient and improved balanced line is suggested with a new sequence of processes and an optimally designed layout which will minimize the idle time and manpower requirement. The derived results demonstrate that the devised model can effectively assist production managers in garment manufacturing organizations in managing line efficiency.

## 1 | Introduction

The garments industry is one of the prominent sources of economic development in developed countries. In the phase of the industrial revolution and tight competition, it is mandatory for the apparel industry to become most competitive in terms of productivity and efficiency. Therefore, designing the assembly line (AL) and pursuing excellence in manufacturing are essential since they give businesses an advantage over competitors [1].

Assigning the work element equally among several workstations is known as line balancing. The main difficulty in optimizing productivity while balancing a production line is assigning a group of tasks to certain workstations while satisfying the precedence relationship and maintaining approximately equal cycle or task time in each stage. For the improvement of the production system, the garment industry identifies bottlenecks and applies simulation techniques to assess the effectiveness [2, 3].

Hence, one of the requirements for establishing a just-in-time manufacturing system is balancing the workloads of the line. Work-in-progress (WIP) and waiting times will increase more quickly in AL workstations where the workload is unequal, which will increase the length and price of the production cycle. So, it is the main task of the garments industry to balance the line by effectively allocating the duties to workstations in a way that is as equitable as possible [4, 5]. Designing the production line effectively eliminates trial and error and reduces the production cost. In the case of the apparel industry, the majority of their products adhere to the standard production process. Before the various garment sections are put together to create a final garment, product parts are built through a subassembly process. The entire process consists of a number of workstations where the specialized task is completed in a certain order with a number of workforces with a variation of skills and thousands of bundles of subassemblies creating the various styles at the same time. The assembling of components and sewing are considered to be the two labor-intensive steps in the production of clothing [6]. Due to the relevance of AL balancing to a variety of industries such as electronics, footwear, automobile, and garments industry, the Assembly Line Balancing Problem (ALBP) has drawn the attention of researchers for a long time [7–9].

The line balancing methods are applied in different industries as well as garment industries with the objective of optimizing the idle time and number of workstations as much as possible [10–12]. The different heuristic techniques such as Largest Candidate Rule (LCR), Kilbridge and Wester method (KWM), and Ranked Positional Weights (RPW) are used to allocate and distribute the work elements in different workstations of the production system based on task time. Bangladesh's apparel businesses use inexpensive labor and ordinary technology, and they are very labor-intensive. Bottlenecking, low productivity, and extended lead times for production are the main challenges faced by the clothing industry of Bangladesh. Furthermore, as it typically involves a large number of manpower and workstations, the sewing or AL is the most important phenomenon in the garment manufacturing industry. The conventional garment production model must be modified to have a more sustainable structure in light of the recent paradigm change in mass customization in order to satisfy consumer demand for flexibility, affordability, and high efficiency.

Deshbandhu Textile Mills is a denim garment manufacturing industry in Bangladesh. Still, the lack of a line balancing mechanism that may account for the stochastic character of the sewing process usually leaves production managers in the garment manufacturing industry unable to execute orders at the allocated time. This case study is conducted with the objective of providing a balanced line with standard time and a balanced layout that will improve efficiency as well as productivity. In this study, three heuristic methods, LCR, KWM, and RPW are implemented and compared to the results obtained to find the best method. Hence, the main objective of this study is to enhance the production line for basic five-pocket pant manufacturing at Deshbandhu Textile Mills Ltd by applying line balancing through simulation modeling. To achieve this, the study targets to meet the following objectives:

a. Examine the existing production line to find inefficiencies, bottlenecks, and places that could be improved.
b. Putting line balancing strategies into practice to increase line efficiency and recommend the best one.

## 2 | Literature Review

For improving the processes in the production system, the work measurement technique is considered to measure the necessary time of processes and determine the best way to complete the task for future improvement. To increase the effectiveness of activities in a production system, gathering time data is needed [13]. Many scholars have used time study to increase productivity and efficiency. For instance, in order to increase the productivity of the operators, Starovoytova investigated the rotary screen-printing process in the textile sector [14]. Khatun, meanwhile, analyzed how time and motion studies affected the apparel industry's production [15]. In contrast, Yemane conducted a study to ascertain the standard minute value (SMV) by control limit analysis and simulation modeling, which was then applied to get rid of bottlenecks, cut down on idle time, and boost productivity [16].

Henry Ford first introduced the AL concept in the early 1900s [17]. Manufacturing companies employ it because it is a highly productive and cost-effective method [18, 19]. Distributing the same amount of work to every station along the line cuts down the time that workers and equipment must wait. AL balancing, or ALB, lowers the risk of a production line interruption. It improves the AL's productivity rate and streamlines the flow [20, 21]. According to specific assembly sequences that outline how the assembling process moves from one station to another, an AL is described as a collection of discrete tasks allocated to a number of workstations connected by a transport mechanism [22, 23]. A collection of precedence connections limits the order in which the tasks can be completed. A task is the smallest indivisible work part. Task time (process time) is the amount of time needed to finish a task. The length of time available at each station as well as the interval between succeeding units turning off the line is known as the cycle time, or station time. Generally speaking, the cycle time is predetermined by the desired rate of production or, alternatively, by the demand for the product in the given period (and/or the given working time for the manufacturing system in that period).

ALs are divided into groups according to factors including product, line shape, and workload. Based on its characteristics, the Simple Assembly line balancing problems (SALBP) are divided into five groups. Every group of issues pertaining to AL design has its own set of goals [24, 25]. The AL's goal is to reduce the number of workstations in the type I problem (SALBP- I), where the cycle time is fixed [26]. The goal of the type II problem (SALBP- II) is to minimize the cycle time, or takt time, with a fixed number of workstations. In a similar vein, type III, IV, and V issues center on how well organized and connected the task is at every AL station [27, 28]. ALs in manufacturing setups are classified into various groups according to their geometries, including U-shaped ALs, Parallel ALs, and traditional straight ALs. The volume and variety of goods that are assembled on ALs have also been used to classify these lines. One kind of product can only be assembled on a single-model AL. Different product models can be assembled on a mixed-model AL. Products are manufactured in batches on multimodel ALs, and setups can be modified over time [29, 30].

Several techniques for balancing production and ALs have been presented and explored in the literature on productivity improvement. The most widely used techniques are the Ranked Position Weight (RPW), the KWM, and the LCR method. These are heuristic techniques, not mathematical formulas and proofs, but understandings and reasoning. These techniques are employed to provide solutions that are decent but not ideal in the sense that they get close to the real optimum. These heuristic techniques are frequently employed to divide and organize the workload and duties among workstations [31]. Selecting the right method for line balancing is crucial. According to the length of standard time (Te), the order of the elements, and the jigs and tools needed, work elements are arranged in descending order and assigned to workstations using the LCR technique [32, 33]. The items in the RPW method are assigned to workstations according to the precedence diagram's position and the size of the RPW [34]. The elements of the KWM, also known as the Colum technique, are assigned to workstations based on where they are located in the precedence diagram [35]. The manufacturing line in this case study has been redesigned using the LCR, Kilbridge & Wester (K&W) technique, and the RPW method. It is mostly used in the textile industry to boost productivity and line efficiency. This opens the door for its use in large-scale industrial settings. It guarantees that there is no or very little idle time while workers move around the workstations [36]. These are the techniques to grasp and apply to industries that produce goods in large quantities, such as textiles, processing, etc.

Literature regarding line balancing in the garments industry of Bangladesh with heuristic approaches is very little as most of the literature found is related to other countries such as India, Kenya, Ethiopia, etc. It is also clear from the literature that a variety of line-balancing strategies were used, and each one showed promise in achieving the objectives. To maximize their potential, a few attempts were made to compare them for real-time applications. Therefore, an attempt is made in this study to choose the best line-balancing strategy for increasing the total line efficiency with real-time data.

## 3 | Research Methodology

In this research, a five-pocket pant is considered as a model for analysis produced by Deshbandhu Textiles Mills Ltd. situated in Uttara Export Processing Zone, Nilphamari. In this unit, all the operations are carried out manually. Primary and secondary data, both quantitative and qualitative, were included in the data obtained. Through time studies, process mapping, observations, and interviews with the managers of the trouser sewing line, primary data have been collected. They included the product model, the trouser AL, the number of operators, the number of workstations, the production process flow, the processing time for each task, the cycle time of each workstation, and the present line balance circumstances. On the other hand, the secondary data comprised the company's organizational structure and brief history, production capacity, data from production planning, effective working hours, weekday schedules, table rating factors, journals, publications, and research findings related to the line balancing subject. The stopwatch time study technique was used to measure operation time for every task component on the AL for pants, and takt time was calculated. From the simulation work, the best method is chosen among the three and suggested for implementation. The methodology followed in the present work is graphically shown in Figure 1. The following assumptions are used during this study.

a. The raw materials entered the production line on schedule, meaning that the cutting department never ran out of supplies.

b. The production line's machinery did not malfunction.

c. The operators and helpers never missed work; thus, the workstations were never stopped as a result of their absence.

d. There was no consideration of overtime during the eight-hour daily manufacturing shift.

The three methods, which are mentioned, the LCR method, KWM, and RPW, have different approaches to arranging the raw data for analyzing the outcomes from them.

### 3.1 | LCR

In the LCRs method, the following steps are involved to reform raw data to calculate the result and analysis. This approach assigns tasks with the largest processing time without exceeding the total cycle time of the station. Steps of the LCRs method are mentioned below, and the flowchart of this method is shown in Figure 2:

a. At first, a precedence diagram is made of the production line.

b. Work elements are placed on the workstation with the largest completion time, and the total time of work elements should not exceed the cycle time of the workstation.

c. When the cycle time exceeds, Work elements move to the next workstation.

d. Repeat steps c and d until all the tasks are assigned to the workstation.

### 3.2 | KWM

Using a heuristic process, work elements are assigned to stations based on where they are in the precedence diagram. This technique is renowned for the consistency in resolving issues that arise with the LCR method, in which an element is chosen based on a large value regardless of where it is located in the precedence diagram. KWM steps are described below, and the flowchart of the method is shown in Figure 3.

- Step 1: Create a precedence diagram.
- Step 2: Determine the cycle time.

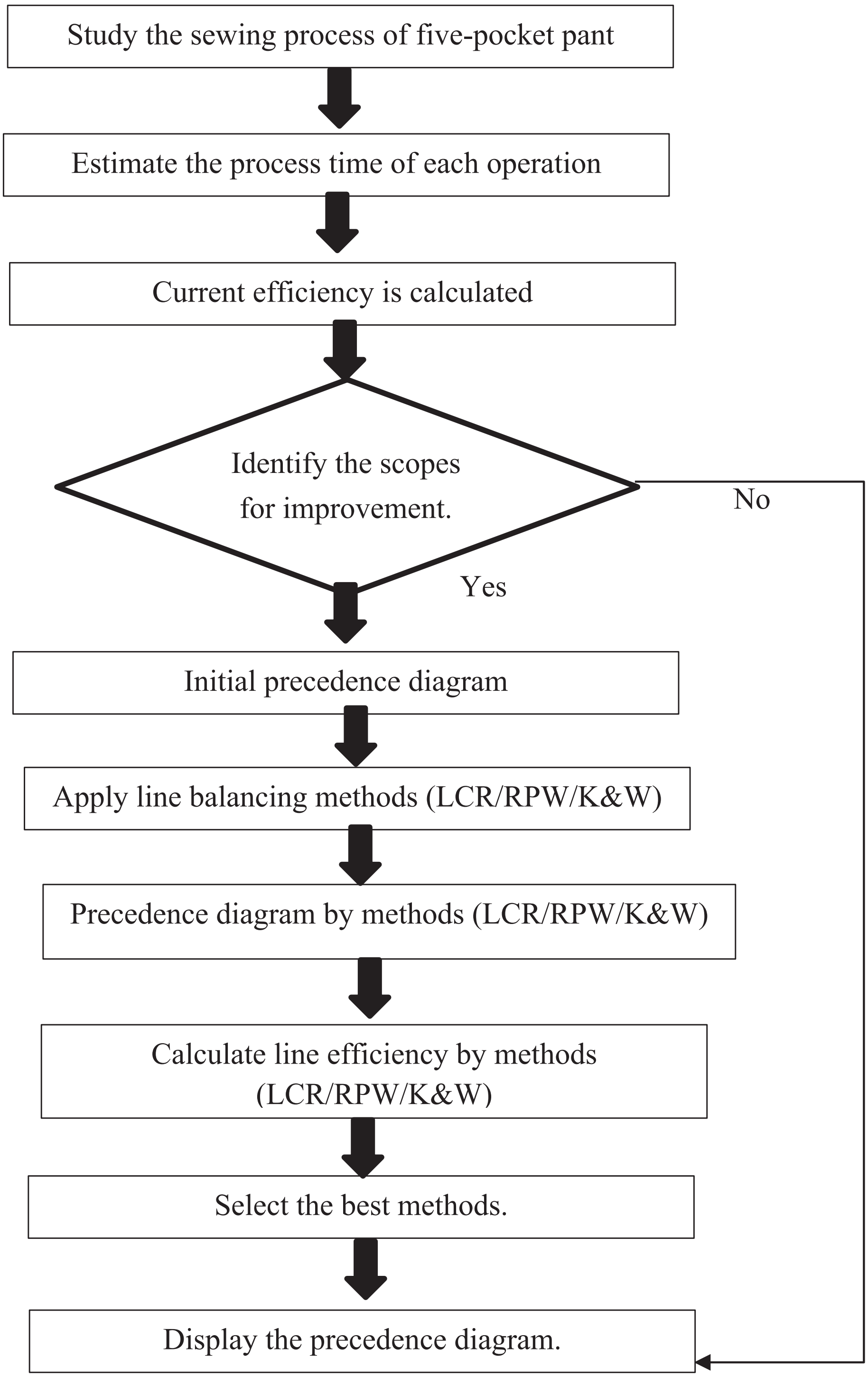


**FIGURE 1** | Process flowchart of methodology.

- Step 3: Place work elements at work stations.
- Step 4: when an element of workstation placement results in a total time of work elements that exceeds the cycle time, working elements are placed in the next workstation.
- Step 5: Repeat steps 3 and 4 until all work elements are placed.
- Step 6: Determine the efficiency.

### 3.3 | RPW Method

Compared to the other approaches listed above, the RPW solution offers a more effective means of allocating the job elements to stations. Using the RPW approach, cycle time can be assigned, and then the number of workstations needed for a production line can be determined, or vice versa. Procedures for the RPW technique are described in the following, and the flowchart of the method is shown in Figure 4:

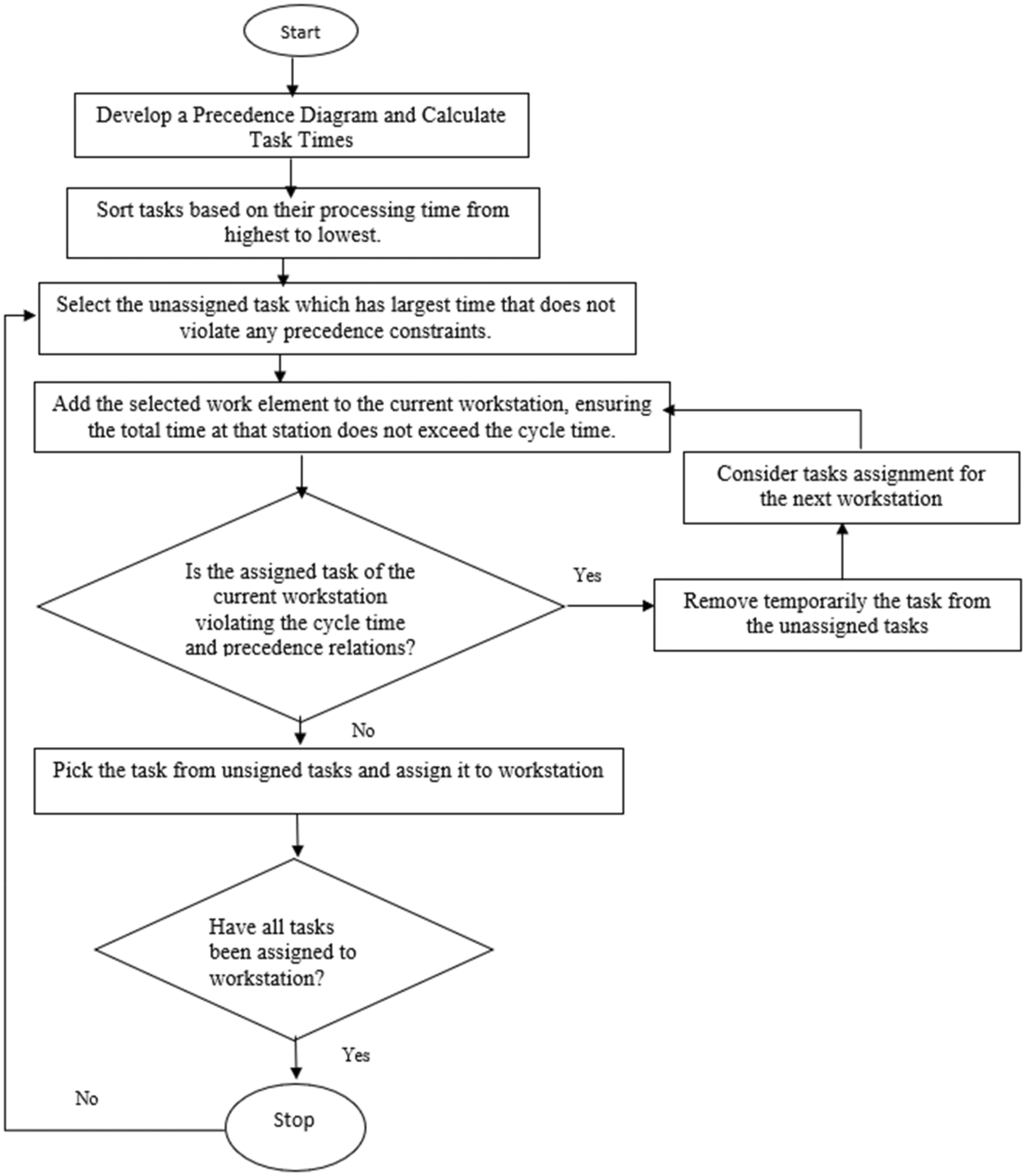


**FIGURE 2** | The flow chart of the LCR line balancing methodology.

- Step 1: Create a precedence diagram.
- Step 2: Find the positional weight for each job element. It is the total amount of time spent on the lengthiest path between the network's first and last operations.
- Step 3: Sort the job items according to their RPW downward.
- Step 4: Designate a station for the work element. Pick the element with the highest RPW. Next, pick the following one. Continue as long as the cycle time is not broken. Observe the priority restrictions as well.
- Step 5: Continue from step 4 until every operation is assigned to a single station.

## 4 | Results Analysis and Discussion

The objective of this research is to enhance the efficiency of the company by optimizing the balance of the production line. Initially, the current scenario of the company was observed. The findings revealed that the organization was unable to meet the target output set in its strategic plan. This conclusion was drawn

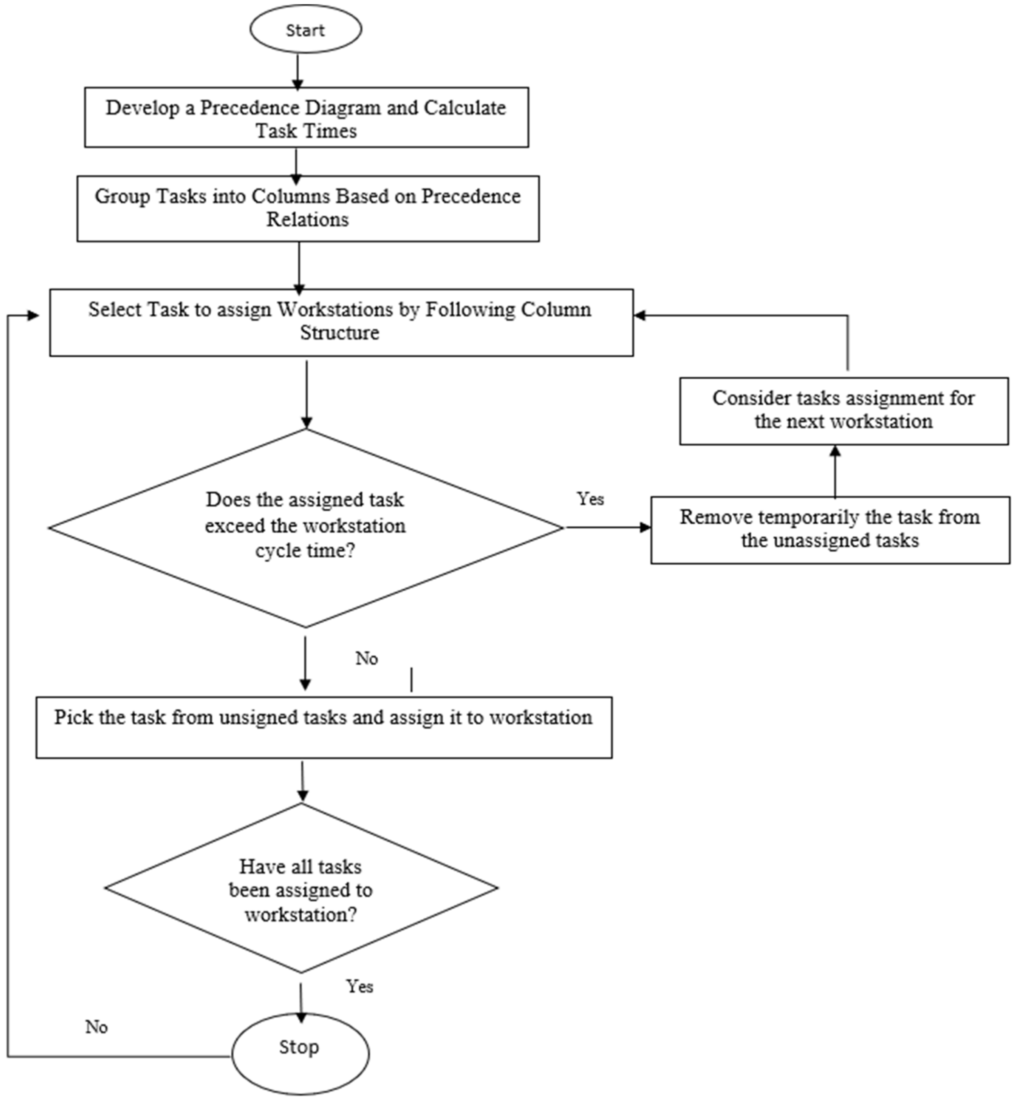


**FIGURE 3** | The flow chart of Kilbridge and Wester's line balancing methodology.

after monitoring production output for several days. To analyze the issue, a five-pocket pant was selected as the sample product. Relevant data related to the production of this item were collected from Deshbandhu Textiles Mills Ltd.

| Data analysis | |
|---|---|
| Demand = 510 units/day =147,390 units/year (289 working days per year) | Standard time = 15.29 min |
| Daily working time = 9 h/day | Hourly production rate Rp = $\frac{147390}{48\times6\times8}$ = 64 unit/h |
| Downtime = 1 h/day | Uptime line efficiency = $\frac{9-1}{9}$ × 100% = 88.88% |
| The line operates = 48 weeks/year 6 shifts/week and 8 h/shift | Cycle time Tc = $\frac{60\times0.8888}{64}$ = 0.833 min |
| Daily Production = 480 units/day | Service available time = 0.833 − 0.018 = 0.815 min |
| Planned efficiency = 70% | Repositioning time loss = 0.018 |

## 4.1 | Company's Current Scenario

A time study is conducted to get the operation time of each process for a finished product, which is shown in Table 1. The current efficiency of the company is calculated and obtained at 43.70%, which is not satisfactory. The company precedence diagram and layout are also shown in Figures 5 and 6.

$$\text{Company efficiency} = \frac{\text{Total station line time}}{\text{Cycle time} \times \text{No.of workstation}} \times 100\%$$

$$= \frac{15.29}{0.833 \times 42} \times 100\%$$

$$= 43.70\%$$

## 4.2 | Line Balancing Using the LCR Method

According to this method, work elements are assigned to a workstation with the largest processing time for tasks as shown in Table 2. The number of workstations and the overall efficiency of the line are calculated.

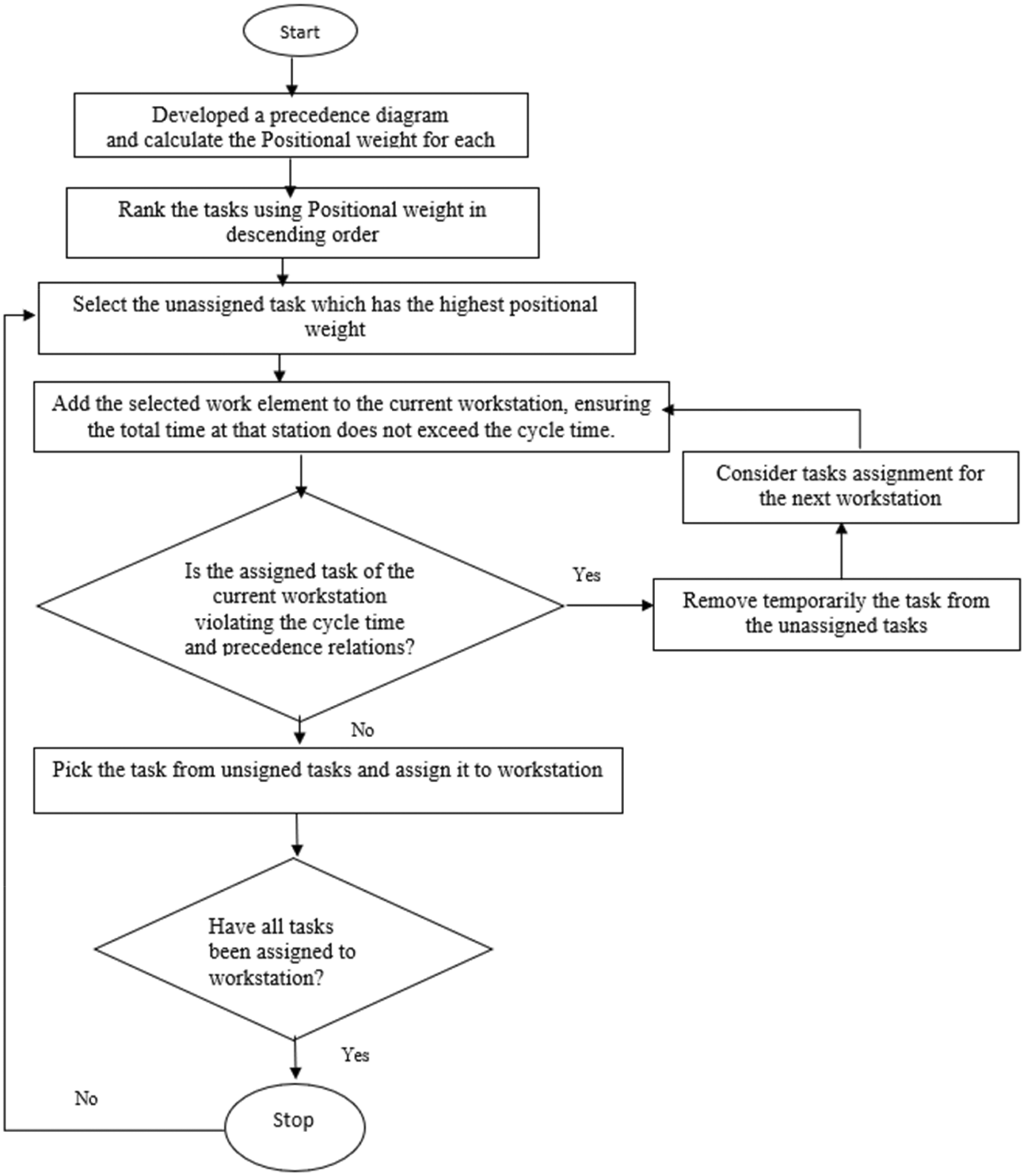


**FIGURE 4** | The flow chart of ranked positional weight line balancing methodology.

Here, (According to data Table 2), No. of workstation = 23

$$\text{Line efficiency} = \frac{\text{Total station line time}}{\text{Cycle time} \times \text{No. of workstation}} \times 100\%$$

$$\text{LCR balance efficiency} = \frac{15.29}{23 \times 0.833} = 79.80\%$$

According to the LCR method, the efficiency obtained is 79.80%. The LCRs precedence diagram and proposed layout are shown in Figures 7 and 8 respectively according to the value of Table 2.

### 4.3 | Line Balancing Using KWM

The work elements are distributed to the workstation based on the position of the task in the precedence diagram according to the K&W method. The assignment of the task to the workstation is shown in Table 3.

Now, we get 24 workstations according to the data of Table 3, and balance efficiency is calculated.

$$\text{Line efficiency} = \frac{\text{Total station line time}}{\text{Cycle time} \times \text{No. of workstation}} \times 100\%$$

**TABLE 1** | Sewing processes and time of five-pocket pant.

| Work element | Operation | Takt time (min) | Work element | Operation | Takt time (min) |
|---|---|---|---|---|---|
| 1 | Coin Pocket Hem*1× | 0.15 | 22 | Back rise t/s | 0.22 |
| 2 | Pocket open; poss mark | 0.24 | 23 | Waistband mark*3× | 0.20 |
| 3 | Coin Pocket make | 0.34 | 24 | Waistband hole tack*2× | 0.32 |
| 4 | Front top facing attach*2× | 0.35 | 25 | Waist band match tack at back pocket | 0.40 |
| 5 | Front lower facing attach with top facing*2× | 0.40 | 26 | Size label attach to back& yoke open: mark | 0.35 |
| 6 | Front pocket open: t/s 1/16 | 0.36 | 27 | Back front matching & loop mark | 0.40 |
| 7 | Front pocket facing serge*2× | 0.24 | 28 | Inseam join | 0.50 |
| 8 | Loop make | 0.16 | 29 | Inseam T/S | 0.38 |
| 9 | Front pocket open: t/s ¼ | 0.38 | 30 | Side seam join | 0.60 |
| 10 | Front rise o/l & attach: w-S-fly, D-fly & S-fly | 0.45 | 31 | Side hip st | 0.42 |
| 11 | S-fly t/s & Zipper attach | 0.35 | 32 | Care label poly & attach at side | 0.32 |
| 12 | D-fly tack & turn | 0.20 | 33 | Loop attach: at waist*5× with shearing | 0.55 |
| 13 | J attach | 0.25 | 34 | Waist band attach | 0.60 |
| 14 | D-fly join with two part t/s | 0.38 | 35 | Waist thread & excess end cut | 0.38 |
| 15 | Front crotch join | 0.32 | 36 | Waist thread remove | 0.40 |
| 16 | Front pocket opening tack | 0.45 | 37 | Mouth close lower | 0.34 |
| 17 | Back pocket hem*2× | 0.10 | 38 | Mouth close upper with mark | 0.45 |
| 18 | Back pocket attach & 2nd outline | 0.38 | 39 | Waist loop tack upper & lower*5× | 0.65 |
| 19 | Back yoke join | 0.38 | 40 | Body & loop BTK*20× | 0.75 |
| 20 | Back yoke t/s | 0.28 | 41 | Bottom hem | 0.48 |
| 21 | Back rise join | 0.24 | 42 | Waist hole*1× | 0.18 |

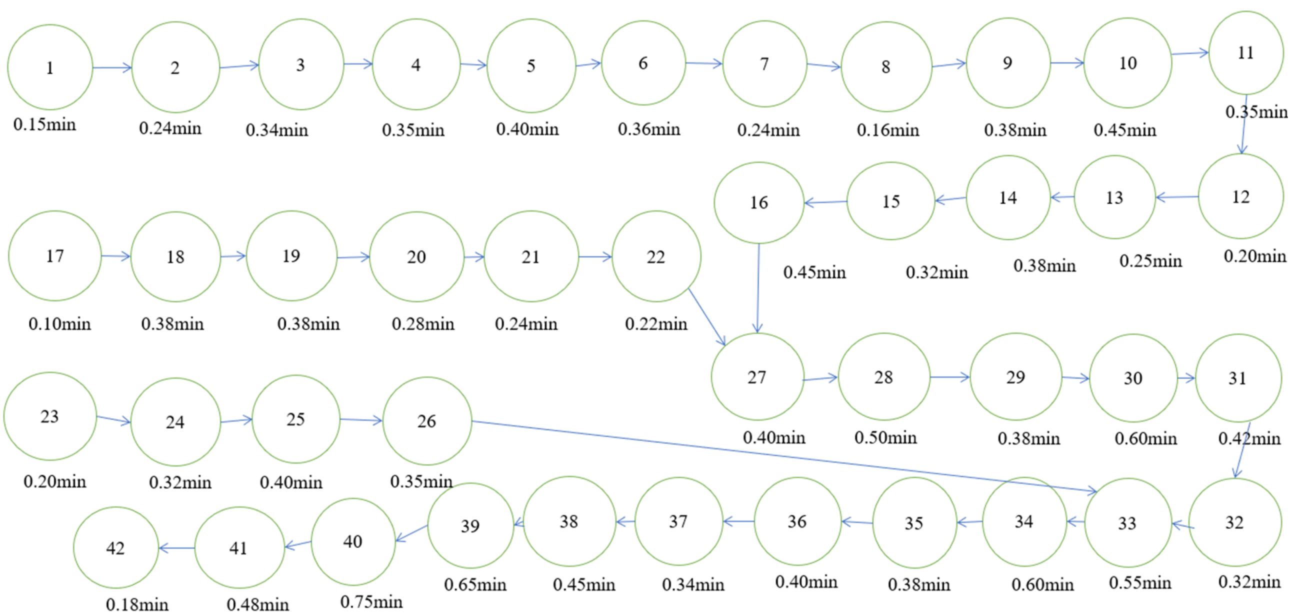


**FIGURE 5** | Current precedence diagram of pant making.

$$\text{K\&W balance efficiency} = \frac{15.29}{24 \times 0.833} \times 100\% = 76.48\%$$

K&W's balance efficiency obtained is 76.48% which is less than the LCRs but greater than the company's current efficiency. K&W's precedence diagram and proposed layout are shown in Figures 9 and 10, respectively, according to the value of Table 3.

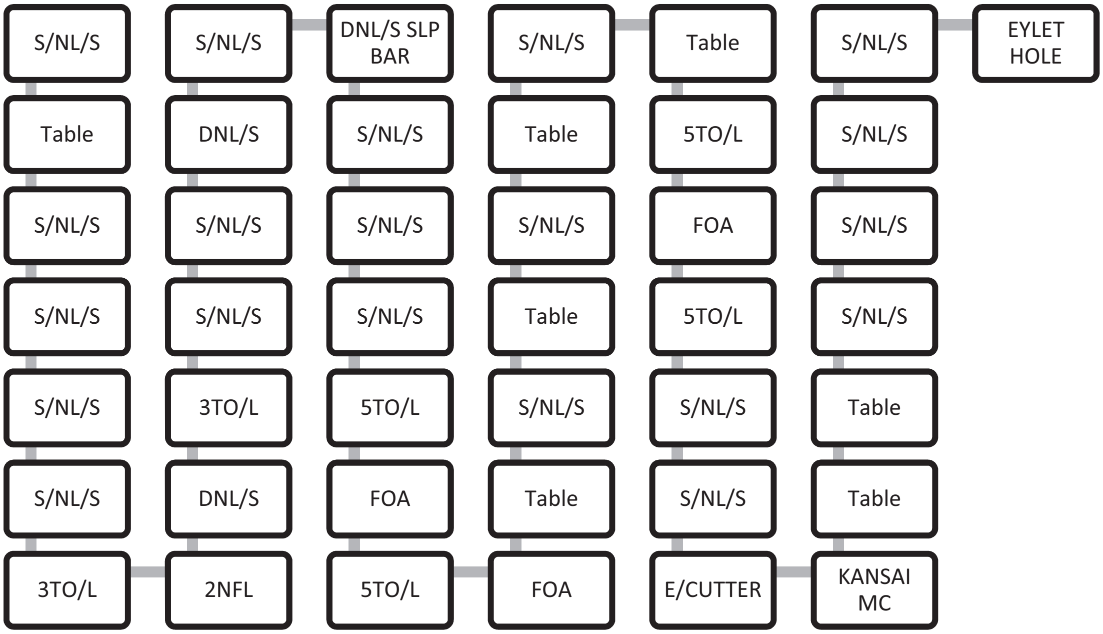


**FIGURE 6** | Current company layout. 2NFL, two-needle flatlock; 3TO/L, three thread overlock; 5TO/L, five thread overlock; DNL/S, double needle lock stich; E/Cutter, edge cutter; FOA, feed of the arm; S/NL/S, single needle lock stich.

**TABLE 2** | Work element assigned to stations according to the largest-candidate rules.

| Station | Work element | Takt time (min) | Station time | Station | Work element | Takt time (min) | Station time |
|---|---|---|---|---|---|---|---|
| 1 | 23 24 | 0.20 0.32 | 0.52 | 13 | 28 | 0.50 | 0.50 |
| 2 | 25 26 | 0.40 0.35 | 0.75 | 14 | 29 | 0.38 | 0.38 |
| 3 | 1 2 3 | 0.15 0.24 0.34 | 0.73 | 15 | 30 | 0.60 | 0.60 |
| 4 | 4 5 | 0.35 0.40 | 0.75 | 16 | 31 32 | 0.42 0.32 | 0.74 |
| 5 | 6 7 8 | 0.36 0.24 0.16 | 0.76 | 17 | 33 | 0.55 | 0.55 |
| 6 | 9 10 | 0.38 0.45 | 0.83 | 18 | 34 | 0.60 | 0.60 |
| 7 | 11 12 13 | 0.35 0.20 0.25 | 0.80 | 19 | 35 36 | 0.38 0.40 | 0.78 |
| 8 | 14 15 | 0.38 0.32 | 0.70 | 20 | 37 38 | 0.34 0.45 | 0.79 |
| 09 | 16 17 | 0.45 0.10 | 0.55 | 21 | 39 | 0.65 | 0.65 |
| 10 | 18 19 | 0.38 0.38 | 0.76 | 22 | 40 | 0.75 | 0.75 |
| 11 | 20 21 22 | 0.28 0.24 0.22 | 0.74 | 23 | 41 42 | 0.48 0.10 | 0.58 |
| 12 | 27 | 0.40 | 0.40 | | | | |

## 4.4 | RPW Method

The RPW of each task is calculated (Table 4) and the tasks are assigned to workstations according to the highest rank positional values of the tasks without violating the precedence relationship and cycle time of workstations, as shown in Table 5.

Here, (According to data Table 5), No. of workstation = 23

And we know,

$$\text{Line efficiency} = \frac{\text{Total station line time}}{\text{Cycle time} \times \text{No. of workstation}} \times 100\%$$

$$\text{RPW balance efficiency} = \frac{15.29}{23 \times 0.833} \times 100\%$$
$$= 79.80\%$$

Here RPW method balance efficiency is 79.80% which is greater than the K&W method but similar to the LCR method. RPW method precedence diagram and proposed layout are shown in Figures 11 and 12 respectively in accordance with Table 5.

Among the three results of the method, as shown in Figure 13, we can see that the efficiency of the RPW method and LCR is 79.80% which is much greater than the existing line efficiency (43.70%). The efficiency of the other method, the KWM, is 76.48% and also performs better than the existing line. The work items are sorted

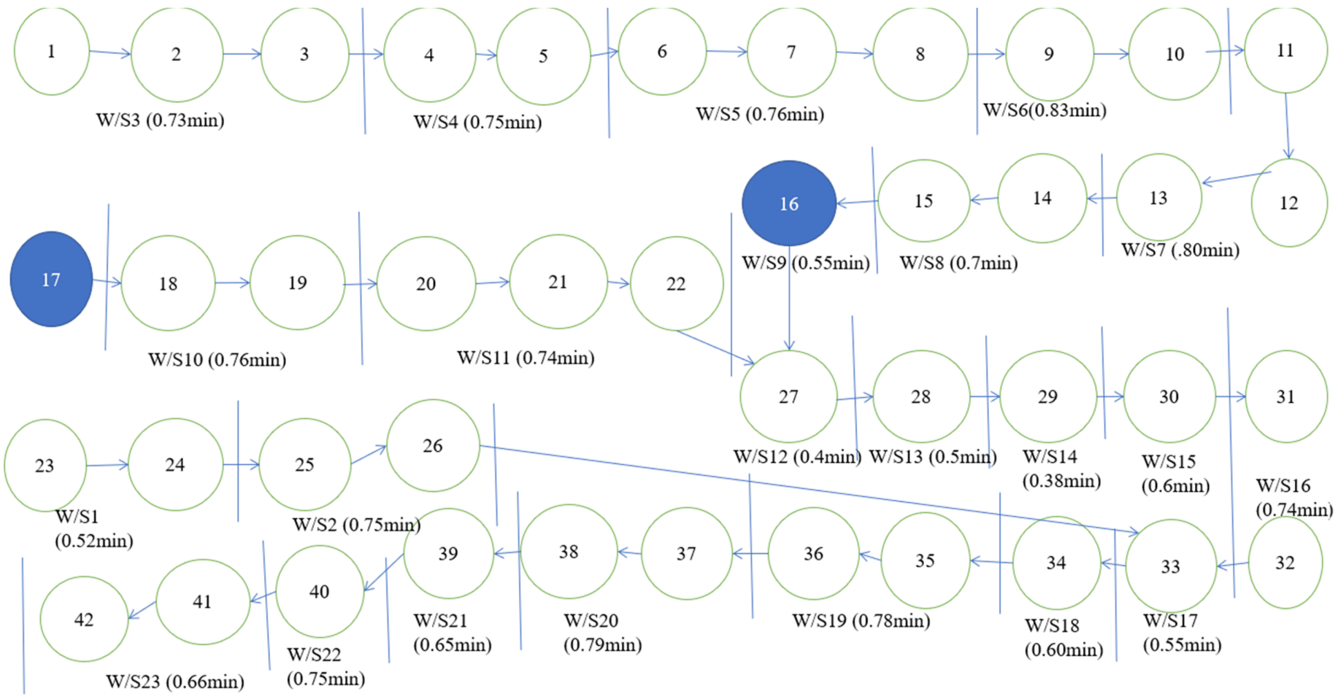


**FIGURE 7** | LCR precedence diagram.

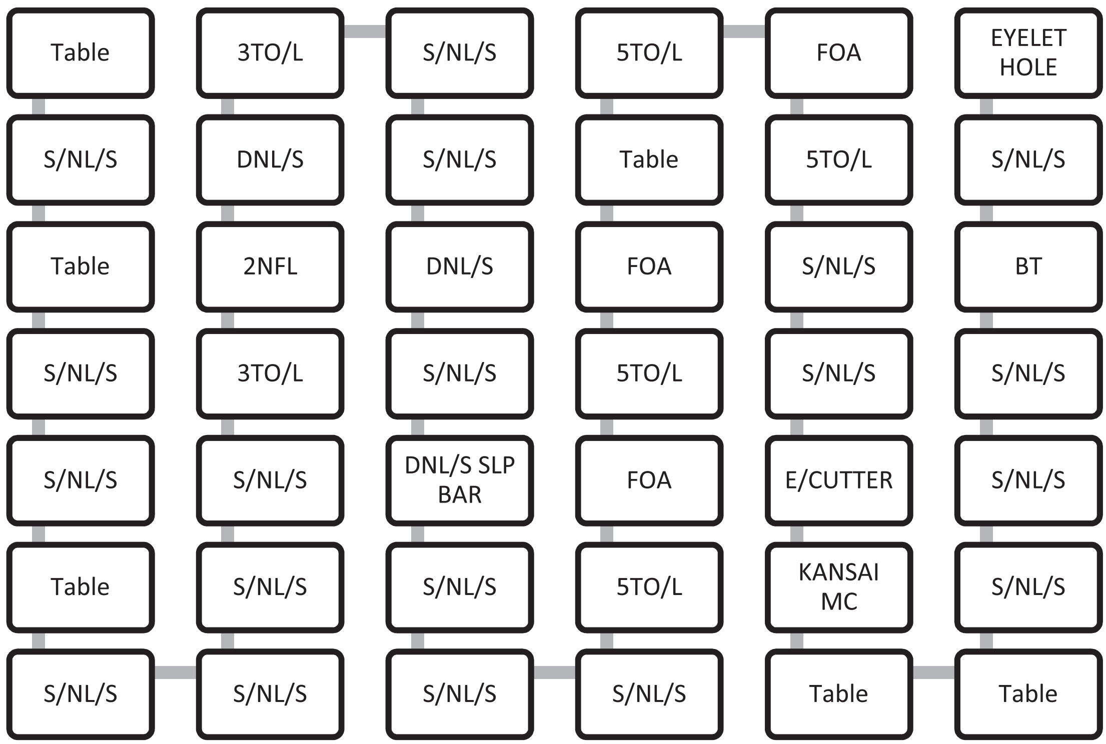


**FIGURE 8** | LCR proposed layout. 2NFL, two-needle flatlock; 3TO/L, three thread overlock; 5TO/L, five thread overlock; DNL/S, double needle lock stich; E/Cutter, edge cutter; FOA, feed of the arm; KANSAI MC, Kansai multi-needle chainstitch machine; S/NL/S, single needle lock stich.

using the LCR approach in decreasing order based on the work element time values. Additionally, the manufacturing AL in this case study was redesigned utilizing the LCR technique, which increased productivity and efficiency while requiring fewer laborers and resources. According to the study, the LCR approach can help process companies balance assembly and manufacturing lines. The KWM is a heuristic process that uses the precedence diagram to determine which work elements should be assigned to which stations. Additionally, the manufacturing industry AL of the process industry was redesigned using the K&W approach, which increased production and efficiency while requiring fewer laborers and resources. However, it is not as effective as the other

**TABLE 3** | K&W method data table to assign stations.

| Station | Work element | Column | Takt time (min) | Station time | Station | Work element | Column | Takt time (min) | Station time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 1 17 | I I I | 0.10 0.15 0.10 | 0.45 | 13 | 27 | XVII | 0.40 | 0.40 |
| 2 | 18 24 | II II | 0.38 0.32 | 0.70 | 14 | 28 | XVIII | 0.50 | 0.50 |
| 3 | 2 25 | II III | 0.24 0.40 | 0.64 | 15 | 29 | XIX | 0.38 | 0.38 |
| 4 | 19 3 | III III | 0.38 0.34 | 0.72 | 16 | 30 | XX | 0.60 | 0.60 |
| 5 | 4 26 | IV IV | 0.35 0.35 | 0.70 | 17 | 31 32 | XXI XXII | 0.42 0.32 | 0.74 |
| 6 | 20 5 | IV V | 0.28 0.40 | 0.68 | 18 | 33 | XXIII | 0.55 | 0.55 |
| 7 | 21 6 | V VI | 0.24 0.36 | 0.60 | 19 | 34 | XXIV | 0.60 | 0.60 |
| 8 | 22 7 8 | VI VII VIII | 0.22 0.24 0.16 | 0.62 | 20 | 35 36 | XXV XXVI | 0.38 0.40 | 0.78 |
| 9 | 9 10 | IX X | 0.38 0.45 | 0.83 | 21 | 37 38 | XXVII XXVIII | 0.34 0.45 | 0.79 |
| 10 | 11 12 13 | XI XII XIII | 0.20 0.25 | 0.80 | 22 | 39 | XXIX | 0.65 | 0.65 |
| 11 | 14 15 | XIV XV | 0.38 0.32 | 0.70 | 23 | 40 | XXX | 0.75 | 0.75 |
| 12 | 16 | XVI | 0.45 | 0.45 | 24 | 41 42 | XXXI XXXII | 0.48 0.18 | 0.66 |

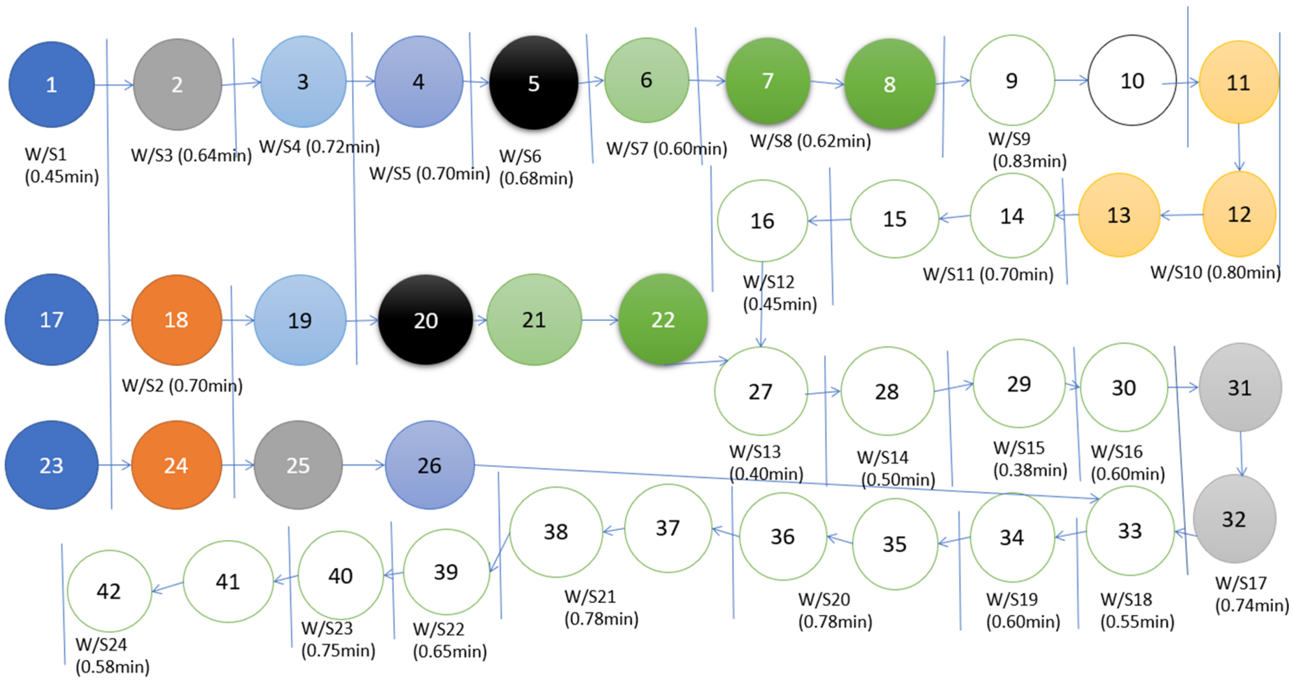


**FIGURE 9** | K&W precedence diagram.

two approaches. Additionally, the RPW Method yielded similar results to the LCR. This resolves the issues with the RPW technique and the LCR, which allows an element to be chosen based just on its high work element time value and ignore its position. The K&W approach typically yields a better line balancing solution. In terms of productivity, labor force, and workstation count, the three heuristics are far superior to the current state of the manufacturing process since they drastically cut down on idle time, or nonvalue-added time, as shown in Table 6. The LCR & RPW approach outperforms the other two models because it takes into account the position as well as the time value of the task element. Therefore, a list of components is created based on their LCR and RPW values. Because of this, the LCR and the RPW approach consistently have higher efficiency, fewer workstations, and fewer personnel. The LCR & RPW approach is strongly advised to increase this project's overall efficiency. In order to increase production and efficiency, the garment industries should use the RPW or LCR approach.

In this research, we use three methods to examine the efficiency of the line, which are RPW, LCR, and K&W methods. Interestingly, RPW and LCR yield the same results in terms of the number of stations and efficiency. Both RPW and LCR will distribute tasks to workstations using a similar logic because the production line has a well-defined and organized sequence of operations. Both approaches are likely to divide jobs in the same way because the precedence restrictions don't vary. However, the consistency of results suggests an ideal line-balancing approach based on the current findings. The production line is modified using the RPW or LCR approach to create a lean line with an ideal layout, which

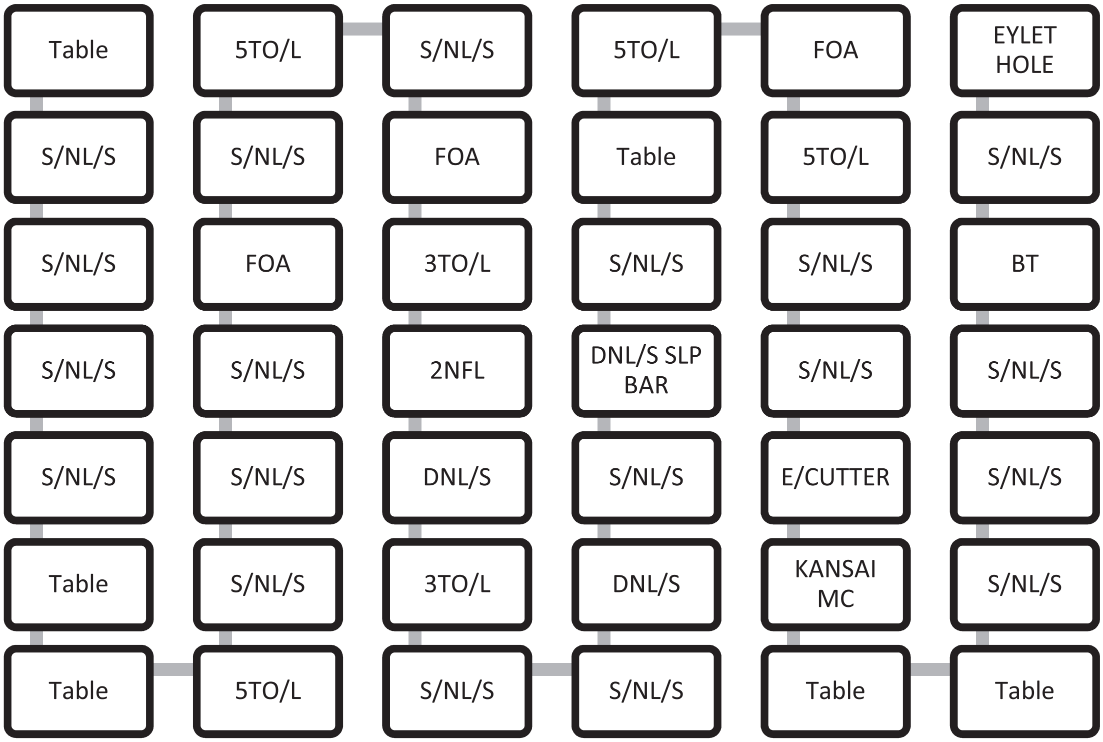


**FIGURE 10** | K&W proposed layout. 2NFL, two-needle flatlock; 3TO/L, three thread overlock; 5TO/L, five thread overlock; DNL/S, double needle lock stich; E/Cutter, edge cutter; FOA, feed of the arm; KANSAI MC, Kansai multi-needle chainstitch machine; S/NL/S, single needle lock stich.

**TABLE 4** | Ranked positional weight calculation for each work element.

| Work element | RPW | Takt time (min) | Preceded by | Work element | RPW | Takt time (min) | Preceded by |
|---|---|---|---|---|---|---|---|
| 1 | 12.42 | 0.15 | — | 22 | 7.62 | 0.22 | 21 |
| 2 | 12.27 | 0.24 | 1 | 23 | 6.05 | 0.20 | — |
| 3 | 12.03 | 0.34 | 2 | 24 | 5.85 | 0.32 | 23 |
| 4 | 11.69 | 0.35 | 3 | 25 | 5.53 | 0.40 | 24 |
| 5 | 11.34 | 0.40 | 4 | 26 | 5.13 | 0.35 | 25 |
| 6 | 10.94 | 0.36 | 5 | 27 | 7.4 | 0.40 | 16, 22 |
| 7 | 10.58 | 0.24 | 6 | 28 | 7.0 | 0.50 | 27 |
| 8 | 10.34 | 0.16 | 7 | 29 | 6.5 | 0.38 | 28 |
| 9 | 10.18 | 0.38 | 8 | 30 | 6.12 | 0.60 | 29 |
| 10 | 9.8 | 0.45 | 9 | 31 | 5.52 | 0.42 | 30 |
| 11 | 9.35 | 0.35 | 10 | 32 | 5.1 | 0.32 | 31 |
| 12 | 9 | 0.20 | 11 | 33 | 4.78 | 0.55 | 26, 32 |
| 13 | 8.8 | 0.25 | 12 | 34 | 4.23 | 0.60 | 33 |
| 14 | 8.55 | 0.38 | 13 | 35 | 3.63 | 0.38 | 34 |
| 15 | 8.17 | 0.32 | 14 | 36 | 3.25 | 0.40 | 35 |
| 16 | 7.85 | 0.45 | 15 | 37 | 2.85 | 0.34 | 36 |
| 17 | 9 | 0.10 | — | 38 | 2.51 | 0.45 | 37 |
| 18 | 8.9 | 0.38 | 17 | 39 | 2.06 | 0.65 | 38 |
| 19 | 8.52 | 0.38 | 18 | 40 | 1.41 | 0.75 | 39 |
| 20 | 8.14 | 0.28 | 19 | 41 | 0.66 | 0.48 | 40 |
| 21 | 7.86 | 0.24 | 20 | 42 | 0.18 | 0.18 | 41 |

**TABLE 5** | Work task assigned to stations according to the ranked position weight values.

| Station | Work element | Takt time (min) | Station time | Station | Work element | Takt time (min) | Station time |
|---|---|---|---|---|---|---|---|
| 1 | 1 2 3 | 0.15 0.24 0.34 | 0.73 | 13 | 28 | 0.50 | 0.50 |
| 2 | 4 5 | 0.35 0.40 | 0.75 | 14 | 29 | 0.38 | 0.38 |
| 3 | 6 7 8 | 0.34 0.24 0.16 | 0.76 | 15 | 30 | 0.60 | 0.60 |
| 4 | 9 10 | 0.38 0.45 | 0.83 | 16 | 31 32 | 0.42 0.32 | 0.74 |
| 5 | 11 12 13 | 0.35 0.20 0.25 | 0.80 | 17 | 33 | 0.55 | 0.55 |
| 6 | 14 15 | 0.38 0.32 | 0.7 | 18 | 34 | 0.60 | 0.60 |
| 7 | 16 17 | 0.45 0.10 | 0.55 | 19 | 35 36 | 0.38 0.40 | 0.78 |
| 8 | 18 19 | 0.38 0.38 | 0.76 | 20 | 37 38 | 0.34 0.45 | 0.79 |
| 9 | 20 21 22 | 0.28 0.24 0.22 | 0.74 | 21 | 39 | 0.65 | 0.65 |
| 10 | 23 24 | 0.20 0.32 | 0.52 | 22 | 40 | 0.75 | 0.75 |
| 11 | 25 26 | 0.40 0.35 | 0.75 | 23 | 41 42 | 0.48 0.18 | 0.66 |
| 12 | 27 | 0.40 | 0.40 | | | | |

Abbreviations: 2NFL, two-needle flatlock; 3TO/L, three thread overlock; 5TO/L, five thread overlock; DNL/S, double needle lock stich; E/Cutter, edge cutter; FOA, feed of the arm; KANSAI MC, Kansai multi-needle chainstitch machine; S/NL/S, single needle lock stich.

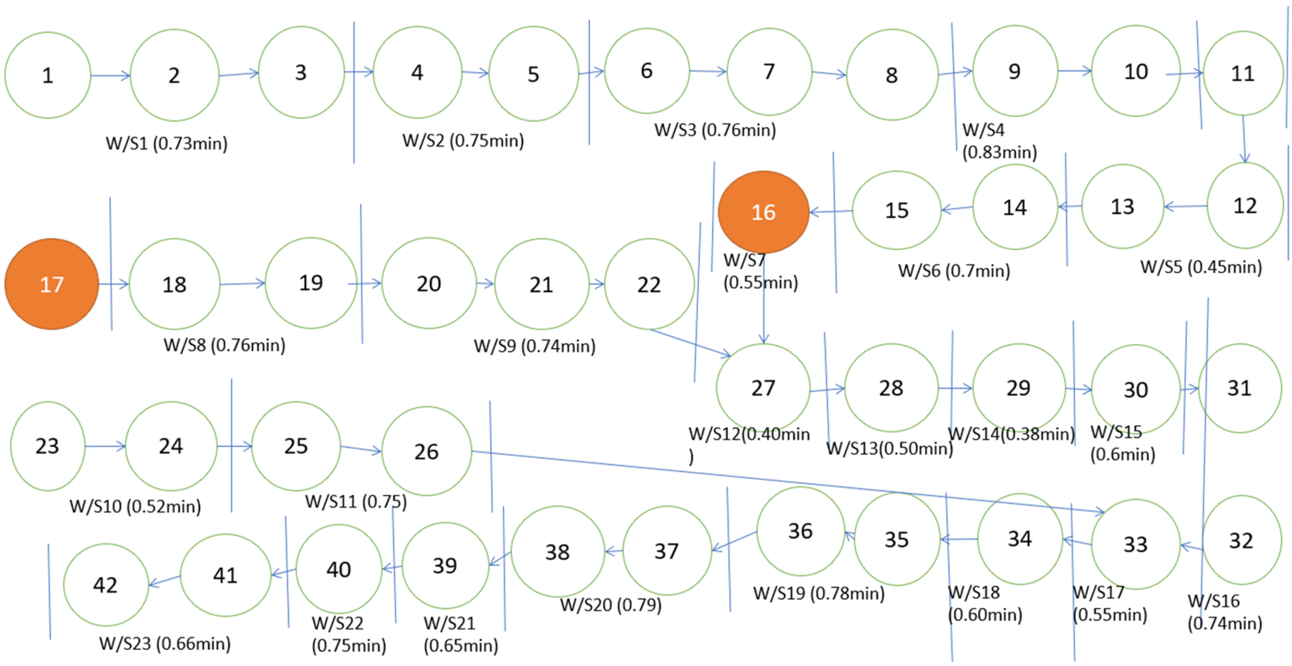


**FIGURE 11** | RPW precedence diagram.

largely improves productivity. The existing layout's area was calculated, and the machines were rearranged to reduce the layout's overall size. In accordance with the operation sequence, the machines are maintained in a single straight line. The last operation's final garment is thoroughly inspected, and any flaws are promptly fixed.

## 5 | Conclusion

This study investigates the line efficiency challenges in the garment manufacturing industry, highlighting the significant impact of precise machine positioning on overall efficiency. In the initial scenario, the company's efficiency was recorded at just 43.70%. To assess line balancing, three heuristic methods were applied: the RPW technique, the K&W column method, and the LCR. The results revealed that all three heuristics substantially outperformed the initial efficiency. Both RPW and LCR achieved approximately 79.80% efficiency, a remarkable improvement from the original 43.70%. The K&W method also demonstrated significant enhancement, achieving about 76.48%, closely aligning with the results of the other two methods. Therefore, to optimize line efficiency, the implementation of the RPW technique and the LCR is recommended for the production line.

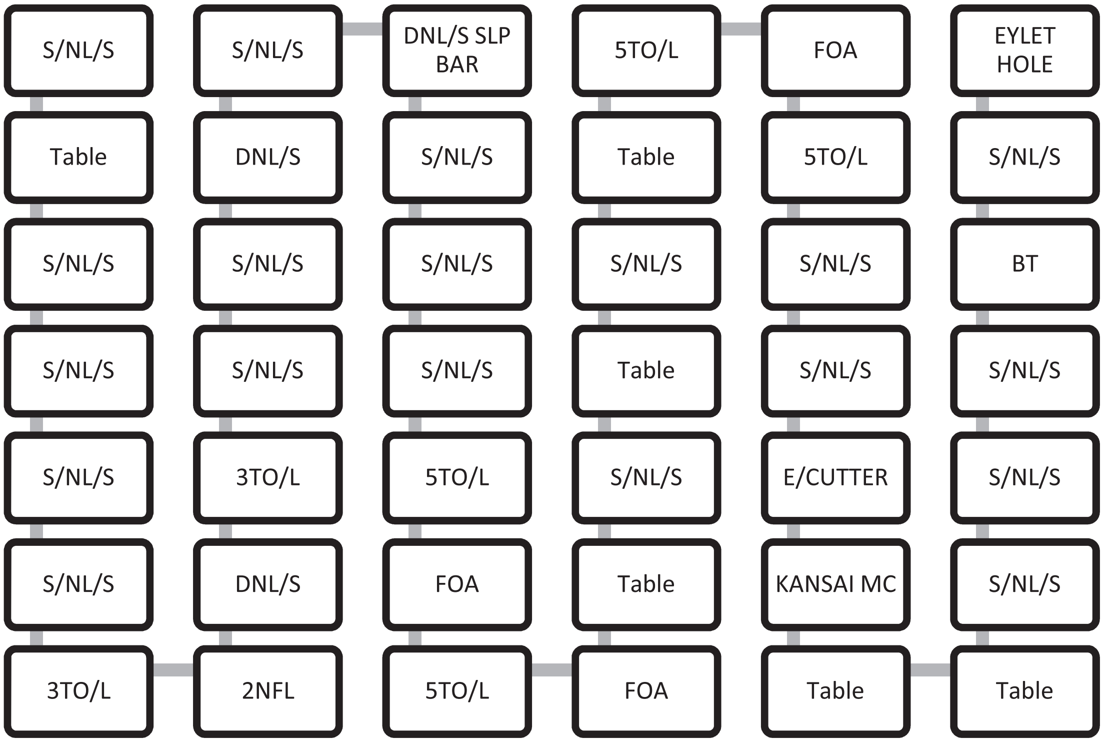


**FIGURE 12** | RPW proposed layout. 2NFL, two-needle flatlock; 3TO/L, three thread overlock; 5TO/L, five thread overlock; DNL/S, double needle lock stich; E/Cutter, edge cutter; FOA, feed of the arm; KANSAI MC, Kansai multi-needle chainstitch machine; S/NL/S, single needle lock stich.

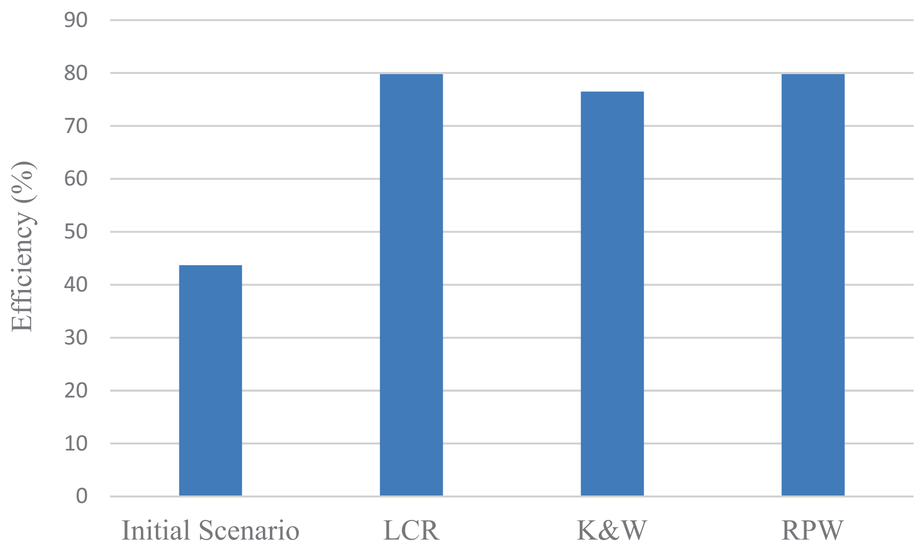


**FIGURE 13** | Comparison of line efficiency of the methods.

**TABLE 6** | Comparison of efficiency among different line balancing techniques.

| Serial number | Performance indicators | Initial scenario | LCR | K&W | RPW |
|---|---|---|---|---|---|
| 1 | Number of workstations | 42 | 23 | 24 | 23 |
| 2 | Task time | 15.29 | 15.29 | 15.29 | 15.29 |
| 3 | Line efficiency | 43.70 | 79.80 | 76.48 | 79.80 |

Line-balancing heuristic methods are relatively simple and easy to use and require less specialized knowledge and training than more complex methods. There are some limitations also as heuristics may not always provide the optimal solution to a line balancing problem, resulting in reduced efficiency and productivity. In future research, it is recommended to implement different meta-heuristic methods and simulation approaches with mathematical optimization for complex line balancing problems with different variables.

In future research, the researchers advise taking into account additional variables, such as the performance and skill levels of employees and the capabilities of each type of equipment utilized in the production process while utilizing the open innovation principles. This could take the kind of data collection tools or apps, information sharing between businesses through production scheduling, or solutions for different issues that crop up.

## Author Contributions

**Mst. Anjuman Ara:** writing – original draft, supervision, project administration, conceptualization. **Nafisa Anjum:** methodology, formal analysis, data curation, investigation. **Dilir Ahbab:** methodology, formal analysis, data curation, investigation. **Mushfica Takia Sidiika:** methodology, investigation, validation, formal analysis, data curation. **Risat Rimi Chowdhury:** conceptualization, supervision, project administration, validation.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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