Improvement of garment assembly line efficiency using line balancing technique

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Abstract
The current competitiveness of garment manufacturing industries is highly dependent on ability to improve efficiency and effectiveness of resource utilization through proper application of industrial engineering techniques such as line balancing and time study. However, very few apparel industries have comprehended industrial engineering function due to little knowledge on practical application of industrial engineering techniques. The present study aimed at balancing a trouser assembly line using the ranked positional weight technique to increase the line efficiency as well as minimize the number of workstations without violating the constraints: precedence relations, cycle time, and resource type. The empirical study was conducted at Southern Range Nyanza Limited (NYTIL) garment manufacturing facility to demonstrate the practical application of ranked positional weight line balancing technique. Results showed that ranked positional weight method is suitable only for assembly line balancing with no constraint on the resource. However, most complex garment assembly lines consist of a number of different machine types rendering ranked positional weight method practically ineffective for improving line efficiency of a complex garment assembly line. Therefore, profound line balancing using simulation-based optimization to improve the line efficiency of complex garment assembly line should be investigated.

KEYWORDS
assembly line, heuristic line balancing, line efficiency, performance indicators, ranked positional weight, resource constraints

1 INTRODUCTION

Garment manufacturing is one of the oldest, largest, labor intensive, and most dependable industries for developing countries in terms of export-oriented industrialization.1 In this new era of industrial revolution and tough competition,2 it is not just a matter of being the best but to survive long enough in the world market. Thus, for garment manufacturers to remain competitive in the global market, they must be able to respond rapidly to changes in customer demand by improving their productivity3,4 and efficiency.5 This is because productivity and efficiency are the major aspects that determine...
the profits gained or success of any business. Therefore, design of the assembly line and continuous improvement in manufacturing to attain excellence is a requirement since it gives a cutting edge over competitors.

Southern Range Nyanza Limited (NYTIL) is a vertically integrated textile industry with garment manufacturing as the most crucial department in this firm. This is because garment manufacturing is a value addition process and increases profits for this company. However, the production managers in garment manufacturing are frequently faced with the issue of being unable to complete the orders at the scheduled time due to unavailability of a line balancing procedure that could encompass the stochastic nature of the sewing process. The stochastic task time is normally caused by variability of sewing times, machine breakdowns, correcting defective products, and operator breakings such as for changing bobbins and drinking water. Efficient garment manufacturing can be achieved through proper design of paced assembly or sewing line.

Assembly line design problem consists of grouping and assigning a given set of tasks to a number of workstations so as to reduce idle time, labor cost, and maximize the throughput as well as improve line efficiency without violating the number of precedence constraints. This problem is also known as the assembly line balancing problem. Assembly line balancing problems are among the well-known problems in manufacturing systems that belong to non-polynomial (NP)-hard class of problems or complex combinatorial problem. This has captured the interest of researchers in the recent years. In essence, several techniques have been developed and adopted in solving the assembly line balancing problem. The most commonly applied line balancing techniques in apparel industry include heuristics, metaheuristics, simulation, and hybrid approaches. The heuristic approach bases on logic (simple priority rules) and common sense rather than on mathematical proof and is capable of generating one or a few feasible solutions. The most commonly used heuristic line balancing method in apparel industry is ranked positional weight. Although heuristic is one of the oldest line balancing techniques, its application in apparel industries are enormous. This is because heuristic technique provides a simple and better way to plan the sewing lines within a reasonable time than other line balancing techniques. Despite it being an old line balancing technique, very few garment manufacturing industries have comprehended heuristic method due to inadequacy of information and literature on its practical applications.

In this study, deterministic task time has been assumed in garment assembly line balancing with the simplest heuristic technique known as ranked positional weight. The current paper demonstrates line balancing using ranked positional weight with consideration of resource constraint and it is organized as follows: Section 2 briefly provide the relevant literature on the study, while section 3 describes the objective and the methodology of the study. Finally, section 4 presents the results and discussions on the different line balancing scenarios.

2 LITERATURE REVIEW

Time study is the work measurement technique to determine the baseline for future improvement. It measures the time necessary for work process to be completed using the best ways. Collecting times data are absolute requirements for improving the efficiency of operations in a production system. Time study has been used by a number of researchers for productivity and efficiency improvement. For instance, Starovoytova studied rotary screen printing operation in a textile industry so as to improve the operators' performance efficiency. While Khatun studied the effect of time and motion study on productivity in garment sector. Nabi et al. on the other hand undertook a time study to determine the standard minute value (SMV), which was subsequently used to eliminate bottlenecks, reduce idle time, and improve efficiency.

At present, line balancing techniques have received much attention than other line efficiency and process improvement techniques such as lean manufacturing (VSM), Lean-six sigma, Six sigma, and hybrid approach (lean manufacturing and line balancing).

Line balancing techniques involve several constraints that have to be put into consideration for example task assignment, task precedence, cycle time, and resource constraints. This makes line balancing an NP-hard or complex combinatorial problem. Vast researchers have applied line balancing technique for improving performance of assembly lines. Fathi et al. investigated the efficiency of the most commonly used performance measures for minimizing the number of workstations in addressing simple assembly line balancing problem for both straight and U-shaped lines. Kayar and Akalin compared heuristic and simulation methods applied to the apparel line balancing problem. The authors postulated that both techniques can be used efficiently for balancing of an assembly line.
A number of authors focused their studies on comparison of the different techniques for heuristic line balancing. Tomar and Manoria\(^42\) for example applied heuristic-based ranked positional weight method, largest candidate rule, and Computer Method for Sequencing Operations for Assembly Lines (COMSOAL) method to increase the efficiency of an assembly line. Their report showed that all heuristic rules can produce good solutions for the straight-line balancing problem. A similar comparative evaluation was performed by Türkmên et al\(^{15}\) who concluded that all heuristic line balancing techniques could be applied to readymade garment assembly line. Similarly, Jha and Khan\(^{43}\) made a comparison between largest candidate rule, Kilbridge and wester column method and ranked positional weight method. The authors hinted that all the three methods showed better efficiency. However, they reiterated that largest candidate rule is superior to the other methods. In addition, Haq et al.\(^{44}\) compared ranked positional weight method, critical path method, and the shortest processing time. The authors inferred that ranked positional weight method assumes deterministic task time and provides acceptable solution that can solve assembly line balancing problem. In another such concerted investigation by Khan and Jha,\(^{45}\) it was reported that the standard operating time can be well evaluated with the application of ranked positional weight method in the production line.

 Ranked positional weight method also known as Helgeson and Birnie was coined by Helgeson and Birnie at General Electric Company in 1961.\(^{46}\) It is one of the most commonly used heuristic line balancing techniques that has drawn the interest of researchers in the recent years\(^{47}\) because of its capability of providing higher line efficiency than the other counterparts such as probabilistic line balancing technique, Hoffman method, and Kilbridge and wester column method.\(^{24,48}\) Several studies have applied ranked positional weight method for improving efficiency and productivity of garment assembly line. For example, Ikhsan et al.\(^{16}\) used ranked positional weight method for allocation of work elements or tasks to specific workstations. The authors obtained the line efficiency of 84.86% and balance delay of 15.14%. Karabay\(^{49}\) compared ranked positional weight method with two manual or practical line balancing techniques. The author achieved line efficiency of 95.1% and smoothness index of 19.84, which was quite superior than the two manual line balancing techniques. Based on the cited studies, ranked positional weight technique was noted to be suitable for improving garment assembly line efficiency. In essence, ranked positional weight heuristic line balancing technique was used to achieve improved line efficiency of a complex trouser assembly line in this study.

### 3 | OBJECTIVE AND METHODOLOGY

#### 3.1 | Objective

This research was conducted in Southern Range Nyanza Limited (NYTIL) to balance its garment assembly line using the ranked positional weight method so as to minimize the number of workstations as well as increase line efficiency without violating the precedence relations, cycle time, and resource constraints.

#### 3.2 | Data collection

The data obtained included qualitative and quantitative primary and secondary data. Primary data were obtained through observations, process mapping, time study, and interviews with the trouser sewing line supervisors. They included product model, trouser assembly line, processing time for each task, production process cycle time of each work station, number of operators, number of workstations, production process flow, and current line balancing conditions. Secondary data on the other hand included a brief history and organizational structure of the company, production capacity, production planning data, effective working hours, schedule weekdays, table rating factors, journals, articles, and research results on the theme line balancing. Further, ABC classification method was applied to prioritize the assembly line for the study. Three product models (cap, trouser, and jacket) were identified with their respective assembly lines. By applying ABC classification method with A-priority given to trouser, B-priority to jacket, and C-priority to cap, only trouser with its assembly line was selected for the study. This selection of the product model was solely based on these criteria: (i) potential to improve overall operations, (ii) potential to impact other products, (iii) economic consideration. Table 1 describes the trouser part (Figure 1) and the required quantity per trouser. The stopwatch time study technique was used to measure operation time for each task element involved in trouser assembly line. For this purpose, continuous stopwatch method was used, and 20 measurements were taken for each task.
| Trouser part | Part name                     | Quantity required per trouser |
|-------------|-------------------------------|-------------------------------|
| a.          | Right flybox                  | 1                             |
| b.          | Second adjustable with lock   | 2                             |
| c.          | Left flybox                   | 1                             |
| d.          | Front part                    | 2 (left and right)            |
| e.          | Knee patch                    | 2 (left and right)            |
| f.          | Side pocket                   | 2 (left and right)            |
| g.          | Bottom rope                   | 2 (left and right)            |
| h.          | Back part                     | 2 (left and right)            |
| i.          | Hip pocket                    | 2 (left and right)            |
| j.          | Hip flap                      | 2 (left and right)            |
| k.          | 1st adjustable without lock   | 2                             |
| l.          | Waist band                    | 1                             |
| m.          | Small loop                    | 7                             |
| n.          | Big loop                      | 7                             |
| o.          | Button                        | 19                            |
| p.          | Knee flap                     | 2 (left and right)            |
| q.          | Knee pocket                   | 2 (left and right)            |
| r.          | Back patch                    | 2 (left and right)            |
| s.          | Company tag and size label    | 2 (tags) and 2 (size label)   |

### TABLE 1 Trouser parts to assembled

#### 3.3 Data processing

Data processing was performed on trouser assembly line time study data. The stages of data processing were carried out as follows;

##### 3.3.1 Calculation of normal time

Normal time is a time when operators start to finish the job without any interference. It is calculated using Equation (1).

\[
\text{Normal time} = \text{Average observed time} \times \text{Rating factor} \tag{1}
\]

The operators’ performances were rated in the range of 75%, 85%, 95%, 105%, 115%, and 125% based on their speed of working and skill level.

##### 3.3.2 Calculation of standard time

Standard time is the requisite time taken by an average skilled operator, working at a normal pace, to perform a specified task using a prescribed method. The calculation of standard time involves computation of time in which the normal time job is multiplied by a factor predetermined allowances as shown in Equation (2).

\[
\text{Standard time} = \text{Normal time} \times (1 + \text{allowances}) \tag{2}
\]

Allowances considered in this study include personal and fatigue allowances, and machine allowances (Table 2). Personal and fatigue are 11% and 9% for women and men, respectively. Adapted from Babu.
3.4  |  Performance indicator calculation

The performance measures: number of workstations, cycle time, idle time, efficiency, balance delay, and smoothness index were first determined for the initial line balancing condition.

3.4.1  |  Minimum number of workstations

The theoretical minimum number of workstations \( (N_t) \) that satisfy workstation cycle time constraints is calculated by Equation (3).

\[
N_t = \frac{\text{total work content time}}{\text{cycle time}}
\]  

(3)
3.4.2 | Cycle time

The cycle time is an amount of time for which a job remains in a workstation. It is also defined as “time gap between two successive products coming out from the assembly line” and it is calculated using Equation (4).

\[
\text{Cycle time} = \frac{\text{Production Time per day}}{\text{Unit required per day}}
\]  

(4)

3.4.3 | Idle time

This is the period in which no operations are held at a station after all operations are completed, and the workpiece stays idle until being moved to the next station. It is calculated using Equation (5).

\[
\text{Total Idle time} = (\text{Number of workstation} \times \text{Cycle time}) - \text{Total standard time}
\]  

(5)

3.4.4 | Balance delay (BD) or loss of balance (LB)

This is the ratio of total idle time over the total time spend on the assembly line. It is defined by Equation (6).

\[
BD = \frac{(\text{Number of tasks} \times \text{Cycle Time}) - \text{Total work content time}}{\text{Number of tasks} \times \text{cycle time}} \times 100
\]  

(6)

3.4.5 | Line efficiency

This is the ratio of total workstations time to the cycle time multiplied by the number of workstations. Line efficiency is the most important performance indicator of any assembly line, and it is calculated employing either Equation (7) or (8).

\[
\text{Line efficiency} = (100 - \text{balance delay})
\]  

(7)

Or

\[
= \frac{\text{Total work content time}}{\text{number of task} \times \text{cycle time}} \times 100
\]  

(8)

3.4.6 | Smoothness index

This is the SD of work distribution between the workstations

\[
\text{Smoothness index} = \sqrt{\frac{\sum_{i=1}^{m} ((T_{\text{Smax}}) - (T_{Si}))^2}{m}}
\]  

(9)

where \( Si \) addresses workstation \( i \), \( T_{Si} \) is the total processing times of the tasks assigned to workstation \( Si \), \( m \) is the number of workstations, \( T_{\text{Smax}} \) is the maximum workstation time selected from among the workstations total time.

3.5 | Line balancing

After knowing the condition of the initial state trouser assembly lines, line balancing was performed by using heuristic-based ranked positional weight method. The following procedures for ranked positional weight method were adopted in this study\(^{47,51}\).
In the present study, ranked positional weight method as illustrated in Figure 2 was applied to balance trouser assembly line in two different scenarios as follows:

Scenario 1: Line balancing was done without violating cycle time and precedence constraints.
Scenario 2: Line balancing was done without violating the cycle time, machine type, or resource constraints and precedence constraints.

## RESULTS AND DISCUSSION

### 4.1 Initial line balancing condition

Table 3 shows the calculated standard time for each task, the task precedence relation, and the ranked positional weight for each task. The solution table (see Appendix) for ranked positional weight was also developed. The precedence diagram (Figure 3) shows the relation between 65 tasks (numbers above or below the circles) assigned to 61 workstations (number in the circles). The workstations are linked by the arrows to show how tasks are performed following precedence relation. The precedence relation is the order or sequence by which tasks are supposed to be performed by the operators or helpers on the assembly line.
### TABLE 3  Standard time trouser assembly line

| Task number | Task descriptions                  | Resource | Precedence relation | ST (minute) | RPW   |
|-------------|------------------------------------|----------|---------------------|-------------|-------|
| 1           | Buttonhole on left flybox          | BH       | -                   | 0.315       | 24.959|
| 2           | Front rise overlocks               | 3thread O/L | 1             | 0.283       | 24.644|
| 3           | Knee patch attaches                | SN/L     | 2                   | 0.929       | 24.361|
| 4           | Side pocket flatlock               | F/L      | -                   | 0.352       | 23.982|
| 5           | Side pocket overlocks              | 5 thread O/L | 4             | 0.198       | 23.631|
| 6           | Right flybox overlock              | 5 thread O/L | -             | 0.334       | 22.498|
| 7           | Side pocket attaches               | SN/L     | 3–5                | 0.577       | 23.432|
| 8           | Side pocket topstitches            | SN/L     | 7                   | 0.691       | 22.855|
| 9           | Right flybox attach                | SN/L     | 6–8                | 0.701       | 22.164|
| 10          | Fly attach                         | SN/L     | 9                   | 0.695       | 21.463|
| 11          | Front prep bundling                | Helper   | 10                  | 0.373       | 20.767|
| 12          | Back marking                       | Helper   | -                   | 0.214       | 23.987|
| 13          | Back patch pressing                | Helper   | -                   | 1.356       | 25.128|
| 14          | Back patch attaches                | SN/L     | 12-13               | 0.534       | 23.773|
| 15          | Hip pocket cutting                 | AWM      | 14                  | 0.247       | 23.239|
| 16          | Hip pocket overlocks               | 5 thread O/L | 15             | 0.927       | 22.992|
| 17          | Hip flap folding                   | Helper   | -                   | 0.216       | 22.461|
| 18          | Buttonhole on hip flap             | BH       | 17                  | 0.187       | 23.245|
| 19          | Hip flap runstitch                 | SN/L     | 18                  | 0.331       | 23.058|
| 20          | Hip flap turning                   | TM       | 19                  | 0.240       | 22.727|
| 21          | Hip flap topstitches               | SN/L     | 20                  | 0.421       | 22.487|
| 22          | Hip pocket finish &                | SN/L     | 16-21               | 0.730       | 22.065|
| 23          | Hip flap attaches                  | SN/L     | 22                  | 0.582       | 21.336|
| 24          | Back prep bundling                 | Helper   | 23                  | 0.359       | 20.754|
| 25          | Front & back matching              | Helper   | 11-24               | 0.432       | 20.395|
| 26          | Side seam overlocks                | 5 thread O/L | 25             | 1.531       | 19.963|
| 27          | Side seam topstitches              | F/A      | 26                  | 1.091       | 18.431|
| 28          | Knee pocket marking                | Helper   | 27                  | 0.362       | 17.341|
| 29          | Knee pocket folding                | Helper   | -                   | 0.235       | 22.095|
| 30          | Knee pocket topstitch              | SN/L     | 29                  | 1.163       | 21.860|
| 31          | Knee pocket tacking                | SN/L     | 30                  | 0.558       | 20.697|
| 32          | Knee pocket overlocks              | 3 thread O/L | 31             | 0.238       | 20.139|
| 33          | Knee pocket hemming                | SN/L     | 32                  | 1.270       | 19.901|
| 34          | Knee pocket ironing                | Iron press | 33             | 1.652       | 18.631|
| 35          | Knee pocket attaches               | SN/L     | 28-34               | 1.251       | 16.979|
| 36          | Knee flap folding                  | Helper   | -                   | 0.403       | 17.294|
| 37          | Buttonhole on k. flap              | BH       | 36                  | 0.202       | 16.891|
| 38          | Knee flap runstitch                | SN/L     | 37                  | 0.221       | 16.689|
| 39          | Knee flap turning                  | TM       | 38                  | 0.349       | 16.468|
| 40          | Knee flap topstitches              | SN/L     | 39                  | 0.392       | 16.119|

(Continues)
| Task number | Task descriptions                      | Resource | Precedence relation | ST (minute) | RPW   |
|-------------|----------------------------------------|----------|---------------------|-------------|-------|
| 41          | Knee flap attaches                     | SN/L     | 35–40               | 1.721       | 15.728|
| 42          | Bar tacking                            | BT       | 41                  | 1.560       | 14.007|
| 43          | Back rise overlocks                    | 5 thread O/L | 42                | 0.658       | 12.447|
| 44          | Back rise topstitches                  | DN/L     | 43                  | 0.576       | 11.789|
| 45          | Big loop matching                      | Helper   | -                   | 0.076       | 12.028|
| 46          | Big loop runstitch                     | SN/L     | 45                  | 0.260       | 11.951|
| 47          | Big loop turning                       | TM       | 46                  | 0.151       | 11.691|
| 48          | Big loop topstitches                   | SN/L     | 47                  | 0.233       | 11.540|
| 49          | Big loop button hole                   | BH       | 48                  | 0.095       | 11.307|
| 50          | Small loop runstitch                   | LM       | -                   | 0.149       | 13.181|
| 51          | Small, big loop, and waist band attach | SN/L     | 44-49-50            | 1.819       | 13.031|
| 52          | Waist band topstitch                   | SN/L     | 51                  | 1.129       | 11.213|
| 53          | Waist band closing                     | SN/L     | 52                  | 1.474       | 10.084|
| 54          | Small loop tacking                     | SN/L     | 53                  | 1.685       | 8.609 |
| 55          | Inseam overlock                        | 5 thread O/L | 54                | 0.548       | 6.924 |
| 56          | Trouser turning                        | Helper   | 55                  | 0.355       | 6.376 |
| 57          | inseam topstitch                       | F/A      | 56                  | 0.671       | 6.021 |
| 58          | Adjustable prep                        | Helper   | -                   | 0.142       | 5.492 |
| 59          | 1st adjustable attach                  | SN/L     | 57-58               | 1.252       | 5.350 |
| 60          | Button hole on bottom                  | BH       | 59                  | 0.523       | 4.098 |
| 61          | Adjustable hemming                     | SN/L     | 58                  | 0.164       | 3.739 |
| 62          | second adjustable attach               | SN/L     | 60-61               | 0.688       | 3.575 |
| 63          | Bottom rope attach                     | Helper   | 62                  | 0.884       | 2.691 |
| 64          | Bottom hemming                         | SN/L     | 63                  | 0.913       | 1.808 |
| 65          | Final bar tacking                      | BT       | 64                  | 0.895       | 0.895 |
|             | Total time                             |          |                     | 41.763      |       |

Abbreviations: BH, button hole machine; BT, bartack machine; DN/L, double needle lockstitch; F/A, feed of arm; LM, loop stitching machine; O/L, overlock machine; RPW, ranked positional weight; SN/L, single needle lockstitch; ST, standard time; TM, turning machine.

The calculation of performance indicators for the initial condition is presented as follows.

a. Number of workstations  
   \[ = 61 \]

b. Cycle time  
   \[ = 8 \times \frac{60}{250} \]  
   \[ = 1.92 \]

c. Theoretical minimum number of workstations  
   \[ = \frac{41.763}{1.92} \]  
   \[ = 22 \]

d. Total idle time  
   \[ = (61 \times 1.92) - 41.763 \]  
   \[ = 75.357 \]

e. Balance delay  
   \[ = \frac{(61 \times 1.92 - 41.763)}{61 \times 1.92} \times 100 \]  
   \[ = 64.34\% \]

f. Line efficiency  
   \[ = (100-64.34)\% \]  
   \[ = 35.66\% \]
4.2 | Ranked positional weight line balancing for scenario 1

Ranked positional weight was used to assign tasks to the workstations without violating cycle time (1.92 minutes) and task's precedence relation. The results of the line balancing are presented in Table 4 and illustrated in Figure 4. The workstation total time is summation of each task time assigned in the specified workstation. As shown in Table 4, 65 tasks were assigned to 27 workstations with the total workstations time of 41.763 minutes and the total idle time of 10.077 minutes. However, only workstations number 9, 15, 25, and 27 contributed most to the total idle time. The precedence relations of the 65 assigned tasks in 27 workstations are illustration in Figure 4.

The calculation of performance indicators for scenario 1 is as presented below:

a. Number of workstations
   = 27
b. Cycle time
   = 1.92
c. Total idle time = 27 x 1.92 − 41.763
   = 10.077
d. Balance delay = \( \frac{27 \times 1.92 - 41.763}{27 \times 1.92} \) x 100
   = 19.44%
e. Line efficiency = (100 − 19.44)%
   = 80.56%
f. Smoothness index = \( \sqrt{(1.671 - 1.884)^2 + \cdots + (0.895 - 1.884)^2} \)
   = 2.51.
| Workstation number | Task(s) assigned to workstation | Workstation total time (min(s)) | Workstation idle time (min(s)) |
|-------------------|---------------------------------|---------------------------------|------------------------------|
| 1                 | 13, 1                           | 1.671                           | 0.249                        |
| 2                 | 2, 3, 12                        | 1.426                           | 0.494                        |
| 3                 | 14, 17, 7, 18, 15               | 1.761                           | 0.159                        |
| 4                 | 19, 4, 16                       | 1.610                           | 0.310                        |
| 5                 | 8, 20, 5, 6, 21                 | 1.884                           | 0.036                        |
| 6                 | 9, 29, 22                       | 1.666                           | 0.254                        |
| 7                 | 30, 10                          | 1.858                           | 0.062                        |
| 8                 | 23, 11, 24, 31                  | 1.872                           | 0.048                        |
| 9                 | 25, 32                          | 0.67                            | 1.25                         |
| 10                | 26                              | 1.531                           | 0.389                        |
| 11                | 33                              | 1.27                            | 0.650                        |
| 12                | 34                              | 1.652                           | 0.267                        |
| 13                | 27, 28, 36                      | 1.856                           | 0.064                        |
| 14                | 35, 37, 38                      | 1.674                           | 0.246                        |
| 15                | 39, 40                          | 0.741                           | 1.179                        |
| 16                | 41                              | 1.721                           | 0.199                        |
| 17                | 42, 50                          | 1.709                           | 0.211                        |
| 18                | 51                              | 1.819                           | 0.101                        |
| 19                | 43, 45, 46, 44                  | 1.57                            | 0.350                        |
| 20                | 47, 48, 49, 52                  | 1.608                           | 0.312                        |
| 21                | 53                              | 1.474                           | 0.446                        |
| 22                | 54                              | 1.685                           | 0.235                        |
| 23                | 55, 56, 57, 58                  | 1.716                           | 0.204                        |
| 24                | 59, 60                          | 1.775                           | 0.145                        |
| 25                | 61, 62                          | 0.852                           | 1.068                        |
| 26                | 63, 64                          | 1.797                           | 0.123                        |
| 27                | 65                              | 0.895                           | 1.025                        |
|                   | **41.763**                      | **10.077**                      |                              |

### 4.3 Ranked positional weight line balancing for scenario 2

In the second scenario, the line balancing was done using ranked positional weight without violating workstation cycle time (1.92 minutes), task precedence relation, and resource (machine type and helpers or operators) constraints. The results of line balancing with scenario 2 are presented in Table 5. As shown, 65 trouser assembly line tasks were assigned in 39 workstations with total workstations time of 41.763 minutes and total idle time of 33.117 minutes. The idle time for workstations number 5, 6, 8, 10, 19, 21, 24, 26, 27, 28, 29, 33, 34, 36, 37, 38, and 39 remained very high because of the restrictions on the resource (machine type and helpers) and the precedence relations. The precedence diagram illustrating the relations between 65 tasks in 39 workstations was presented as shown in Figure 5.

The calculation of performance indicators for scenario 2 is presented as follows:

a. Number of workstations  
   = 39

b. Cycle time  
   = 1.92
c. Total idle time = $39 \times 1.92 - 41.763 = 33.117$

d. Balance delay = $\frac{39 \times 1.92 - 41.763}{39 \times 1.92} \times 100 = 44.23\%$

e. Line efficiency = $100 - \text{Balance delay} = (100 - 44.23) = 55.77\%$

f. Smoothness index = $\sqrt{(1.356 - 1.858)^2 + \cdots + (0.895 - 1.858)^2} = 5.71.$

Table 6 compares the initial condition/scenario and the two scenarios from ranked positional weight line balancing technique using the performance indicators: number of workstations, total idle time, balance delay, line efficiency, and smoothness index. From Figure 6, it was observed that scenario 1 produced the most well-balanced assembly line with very low smoothness index (2.51) and high line efficiency (80.56%). This confirmed that minimization of workstations contributes to increase of line efficiency and reduction of smoothness index. The closer the smoothness to zero, the better the line balancing. This result is in accordance to the study conducted by Karabay49 and Ikhsan et al16 that achieved line efficiency of 95.1% and 84.86%, respectively. When the resource constraint is put into consideration, it was difficult to achieve high line efficiency and low smoothness index as with scenario 2. This is because resource constraint normally restricts the number of tasks to be allocated in the workstations even if the cycle time and precedence relations are satisfied. This result confirmed that the power and effectiveness of ranked positional weight method for line balancing decreases as the number of constraints to be considered increases. Therefore, the result of this study is in agreement with the study by Türkmen et al.,15 which stressed that as the number of operations and workstations gets higher, applying heuristic line balancing methods also gets harder, more complex and suffer lower efficiency because of the basic obstacle of their applicability.
| Workstation number | Task(s) assigned to workstation | Workstation total time (min(s)) | Workstation idle time (min(s)) |
|--------------------|--------------------------------|---------------------------------|-------------------------------|
| 1                  | 13                             | 1.356                           | 0.564                         |
| 2                  | 1, 18, 37, 49, 60              | 1.322                           | 0.598                         |
| 3                  | 2, 5, 6, 32                    | 1.053                           | 0.867                         |
| 4                  | 3, 14                          | 1.463                           | 0.457                         |
| 5                  | 12, 17, 29                     | 0.665                           | 1.255                         |
| 6                  | 4                              | 0.352                           | 1.568                         |
| 7                  | 7, 19, 8                       | 1.599                           | 0.321                         |
| 8                  | 15                             | 0.247                           | 1.673                         |
| 9                  | 16                             | 0.927                           | 0.993                         |
| 10                 | 20, 39, 47                     | 0.74                            | 1.18                          |
| 11                 | 21, 9, 22                      | 1.852                           | 0.068                         |
| 12                 | 30, 10                         | 1.858                           | 0.062                         |
| 13                 | 23, 31                         | 1.140                           | 0.780                         |
| 14                 | 11, 24, 25                     | 1.164                           | 0.756                         |
| 15                 | 26                             | 1.531                           | 0.389                         |
| 16                 | 33                             | 1.27                            | 0.650                         |
| 17                 | 34                             | 1.652                           | 0.268                         |
| 18                 | 27                             | 1.091                           | 0.829                         |
| 19                 | 28, 36                         | 0.765                           | 1.155                         |
| 20                 | 35                             | 1.251                           | 0.669                         |
| 21                 | 38, 40                         | 0.613                           | 1.307                         |
| 22                 | 41                             | 1.721                           | 0.199                         |
| 23                 | 42                             | 1.56                            | 0.36                          |
| 24                 | 50                             | 0.149                           | 1.771                         |
| 25                 | 51                             | 1.819                           | 0.101                         |
| 26                 | 43                             | 0.658                           | 1.262                         |
| 27                 | 45, 56, 58                     | 0.576                           | 1.344                         |
| 28                 | 46, 48                         | 0.493                           | 1.427                         |
| 29                 | 44                             | 0.576                           | 1.344                         |
| 30                 | 52                             | 1.129                           | 0.791                         |
| 31                 | 53                             | 1.474                           | 0.446                         |
| 32                 | 54                             | 1.685                           | 0.235                         |
| 33                 | 55                             | 0.548                           | 1.372                         |
| 34                 | 57                             | 0.671                           | 1.249                         |
| 35                 | 59                             | 1.252                           | 0.668                         |
| 36                 | 61, 62                         | 0.852                           | 1.068                         |
| 37                 | 63                             | 0.884                           | 1.036                         |
| 38                 | 64                             | 0.913                           | 1.007                         |
| 39                 | 65                             | 0.895                           | 1.025                         |

Total time = 41.763 33.117
**FIGURE 5** Precedence diagram for scenario 2

### TABLE 6 Comparison of line balancing scenarios

| S/N | Performance indicators | Initial scenario | Scenario 1 | Scenario 2 |
|-----|-------------------------|------------------|------------|------------|
| 1.  | Number of workstations  | 61               | 27         | 39         |
| 2.  | Total idle time (min)   | 75.36            | 10.08      | 33.12      |
| 3.  | Balance delay (%)        | 64.34            | 19.44      | 44.23      |
| 4.  | Line efficiency (%)      | 35.66            | 80.56      | 55.77      |
| 5.  | Smoothness index         | 10.18            | 2.51       | 5.71       |

### 5 | CONCLUSIONS

The aim of this study was to improve a complex trouser assembly line efficiency using ranked positional weight heuristic method and examine its applicability under two-line balancing scenarios (without and with resource constraint). It was found that ranked positional weight method produces a well-balanced assembly line with higher line efficiency when there is no consideration of resource constraint in each workstation. However, it produces low line efficiency when there is resource constraint. This confirmed the ineffectiveness of using ranked positional weight method for complex garment assembly line balancing, which normally consists of more than one resource type rendering line balancing with no resource constraint practically impossible. This limit the applicability of ranked positional weight technique for achieving greater improvement in line efficiency. Nevertheless, this technique can easily be applied to improve the efficiency of a garment assembly line with few and identical machines especially in knit wear garment manufacturing. However,
**FIGURE 6** Comparison of the three scenarios based on five performance indicators

| Performance indicators | initial Scenario | Scenario 1 | Scenario 2 |
|-------------------------|------------------|------------|------------|
| Number of workstations  | 61               | 27         | 39         |
| Idle time               | 75.36            | 10.08      | 33.12      |
| Balance delay           | 64.34            | 19.44      | 44.23      |
| Line efficiency         | 35.66            | 80.56      | 55.77      |
| Smoothness index        | 10.18            | 2.51       | 5.71       |

profound line balancing using simulation-based optimization to improve the efficiency of trouser assembly line should be investigated.

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**CONFLICT OF INTEREST**

The authors declare no potential conflict of interest.

**AUTHOR CONTRIBUTIONS**

Ocident Bongomin: Conceptualization-Lead, Formal analysis-Lead, Investigation-Lead, Methodology-Lead, Project administration-Lead, Writing-original draft-Lead, Writing-review & editing-Lead. Josphat I. Mwasagi: Conceptualization-Supporting, Formal analysis-Supporting, Investigation-Equal, Methodology-Supporting, Project administration-Supporting, Supervision-Lead, Visualization-Supporting, Writing-original draft-Supporting, Writing-review & editing-Supporting. Eric Nganyi: Conceptualization-Supporting, Formal analysis-Supporting, Investigation-Equal, Methodology-Supporting, Project administration-Supporting, Supervision-Lead, Writing-original draft-Supporting, Writing-review & editing-Supporting. Ildephonse Nibikora: Conceptualization-Supporting, Formal analysis-Equal, Investigation-Supporting, Methodology-Supporting, Project administration-Supporting, Supervision-Lead, Writing-original draft-Supporting, Writing-review & editing-Supporting.

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**APPENDIX**

**Ranked positional weight solution table.**

1–65 along the first column represent the tasks numbers and along the first row represent the tasks precedence relation. The last column of the solution table is the ranked positional weight (RPW) for each task. The sign (*) represent the task time of the precedence task and the summation of each precedence task time (*) give the ranked positional weight of the specified task number.