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Improving the Productivity of a Polypropylene Bag Manufacturing Line through Heuristic Line-Balancing Techniques: A Case Study

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Abstract

Productivity in labour-intensive manufacturing depends strongly on how work is distributed among sequential operations. This study applies heuristic line-balancing methods to improve the productivity of the finishing line of a polypropylene (PP) bag factory in Kombolcha, Ethiopia, using the 61 × 100 cm bag, which the company identified as a high-demand model. Data were collected through direct observation, interviews, production records, and stopwatch time study. Standard times were established for nine sequential work elements, and their precedence relationships were defined. The Largest Candidate Rule (LCR), Ranked Positional Weight (RPW), and Kilbridge–Wester (K&W) methods were then applied and evaluated using the number of workstations, line efficiency, balance delay, smoothness index, and production rate. With a total task time of 37.596 s and a cycle time of 14.4 s, the theoretical minimum was 2.61, that is, three workstations. All three heuristics produced the same three-station assignment, giving a line efficiency of 87%, a balance delay of 13%, and a smoothness index of 3.9. Compared with the existing five-station line (68.99% efficiency), the proposed configuration reduced the number of workstations by 40% and raised the calculated production rate from 560.113 to 916.67 pieces/day and the calculated daily output from 56,046 to 81,241.185 pieces, with the same 80 operators. Because the improved configuration is a model-based proposal that has not yet been implemented, these figures represent calculated improvement potential rather than measured post-implementation gains. The findings indicate that heuristic line balancing supported by reliable standard times is a practical, low-cost means of reducing idle time and bottlenecks in labour-intensive PP bag manufacturing.

Keywords: *line balancing; heuristic methods; Largest Candidate Rule; Ranked Positional Weight; Kilbridge–Wester; productivity improvement; standard time; PP bag manufacturing; Ethiopia*

1. Introduction

Productivity is a central determinant of a manufacturing firm's ability to sustain operations, expand, and compete in local and international markets. It is generally defined as the efficiency with which inputs such as labour, machinery, materials, and time are converted into outputs, and it is commonly expressed as the ratio of output to the resources consumed [1], [2]. Improving manufacturing productivity therefore requires firms to identify and remove operational inefficiencies while making fuller use of the resources already available.

In labour-intensive production systems, productivity depends not only on machine performance but also on how work is organised and allocated among operators and workstations. Typical sources of

loss are unbalanced workloads, excessive operator movement, unnecessary material handling, waiting time, and work-in-process (WIP) accumulation, all of which lengthen lead time and lower resource utilisation [3], [4]. Systematic approaches are therefore needed to find and eliminate such waste and to improve the flow of work.

Lean manufacturing is a widely adopted approach to this problem. It improves performance by eliminating non-value-adding activities, producing what is required, when it is required, and in the quantity required [5]. Its adoption in small and medium-sized enterprises (SMEs) in developing economies is typically incremental and shaped by local resource and skill constraints [6],[7],[8]. Among the practices associated with lean production, line balancing is especially relevant to systems in which interdependent operations are performed in sequence.

Line balancing is the allocation of work elements to workstations so that workloads are as even as possible while precedence relationships and cycle-time limits are respected. Where tasks are performed in sequence, an uneven allocation creates bottlenecks at some stations and idle capacity at others, which reduces throughput and line efficiency. The assembly-line balancing problem is combination, and exact methods become difficult to apply as problem size and constraints grow [9] [10]. Simple priority-rule heuristics, such as the Ranked Positional Weight method [11] and the Kilbridge–Wester column method [12], together with the Largest Candidate Rule [13], therefore remain widely used in practice. They require reliable task times and clearly defined precedence relationships.

Empirical applications of these heuristics are concentrated in garment and assembly settings, including several Ethiopian garment studies [3], [14]–[16]. Studies of plastic-bag production, by contrast, have largely examined lean tools such as 5S, kanban, SMED, and TPM, or simulation of the production flow [17] [18], rather than the balancing of manual finishing operations. This leaves limited direct evidence on how classical heuristics perform in the finishing section of a PP bag factory, where cutting, stitching, counting, printing-related handling, and packaging are performed manually in close sequence.

This study was conducted at Hifam/Seid Ali PP Bag Factory in Kombolcha, Ethiopia, established in 2008 E.C. (approximately 2015/16 G.C.). The factory produces PP bags of several sizes (including 72, 65, 55, and 53 cm) mainly for packaging flour, grain, and salt, and its main customers are flour mills. The production process comprises raw-material preparation, weaving, cutting, stitching, printing, and finishing. The principal raw materials are polypropylene (PP), calcium carbonate ($CaCO_3$), colour masterbatch, high-density polyethylene (HDPE), and low-density polyethylene (LDPE), combined according to product requirements. The factory employs more than 300 operators and has an approximate capacity of 70,000 bags per day.

Despite this capacity, the finishing section has experienced persistent productivity problems. Preliminary work place observations and discussions with factory personnel identified excessive movement between cutting and stitching and between stitching and counting/packaging, the absence of standard times for several manual operations, WIP accumulation, and uneven workloads among operators. Together these cause waiting time, operator idle time, and interruptions in production flow, and the lack of reliable standard times makes it difficult to allocate work systematically or to assess the performance of individual workstations.

Factory records confirm a gap between planned and actual output. The finishing section had annual targets of 23,310,660 bags in 2013 E.C. (approximately 2020/21 G.C.) and 21,607,059 bags in 2014 E.C. (approximately 2021/22 G.C.), against actual production of 18,490,638 and 12,820,197 bags, respectively. These figures correspond to 79.3% and 59.3% of target. The factory's own records report 53.4% for 2014 E.C. when production disruptions during the crisis period are taken into account, and a labour productivity of 62.5% against a target line efficiency of 90%. Such a gap indicates a need for systematic intervention to improve resource utilisation and line efficiency.

The objective of this study is therefore to improve the productivity and operational efficiency of a PP bag finishing line by applying heuristic line-balancing techniques based on measured standard task times and defined precedence constraints. Specifically, the study (i) develops standard times and a precedence network for the finishing operations of the 61 × 100 cm bag; (ii) applies and compares the LCR, RPW, and K&W heuristics under identical conditions; and (iii) evaluates the resulting configurations using the number of workstations, line efficiency, balance delay, smoothness index, and production rate. The study contributes context-specific evidence on classical heuristic balancing in a labour-intensive PP bag finishing operation in Ethiopia and links time study directly to the balancing model.

2. Literature Review

2.1 Productivity and workload balance in sequential production

Productivity is the relationship between the output generated and the resources consumed in producing it. In manufacturing, the relevant resources include labour, materials, equipment, energy, capital, and time, and improvement can be achieved by raising output without a proportional increase in inputs, or by maintaining output with fewer inputs. Reviews of the productivity literature emphasis that measurement and improvement must go together and that system-level, rather than purely equipment-level, metrics are needed to locate bottlenecks and hidden capacity [1], [2].

In a sequential production line, the workload assigned to each workstation directly governs overall flow. When one station carries more work than the next, downstream stations wait or upstream stations accumulate WIP; stations with small workloads show excessive idle time. These effects reduce effective capacity and lengthen lead time. Line balancing addresses this structural source of inefficiency by allocating work elements to stations subject to precedence and cycle-time constraints [9], [19].

2.2 Lean manufacturing and line balancing

Lean manufacturing seeks to eliminate activities that add no value from the customer's perspective, emphasising continuous improvement, waste reduction, and smooth flow. The commonly recognised wastes are overproduction, excess inventory, waiting, unnecessary transportation, over-processing, unnecessary motion, and defects [5]. In the present case the most relevant are waiting, transportation, motion, excess WIP, and under-used labour, all of which are frequent consequences of unequal workloads and poorly drawn station boundaries.

Lean adoption in SMEs requires particular attention to organisational resources, workforce capability, and management commitment [7], [8]. A recent systematic review of 123 empirical studies published between 2015 and 2025 found that SMEs in developing countries adopt lean incrementally, through context-specific combinations of tools, and proposed a three-phase model of context-driven lean maturity [6]. Such reviews provide a broad view of lean adoption, but they do not compare individual production-improvement techniques or quantify the effect of alternative balancing heuristics.

Line balancing can be combined with other lean tools. Achmadi et al. [20] combined value stream mapping (VSM) with the RPW method in a defence-industry assembly process (56 tasks, 43 workstations, 155 components) and reduced total assembly cycle time from 5,121 s to 3,620 s, a reduction of about 29%, with improvements in balance delay, line efficiency, and smoothness index. Because the two techniques were applied together, however, the separate contribution of each cannot be isolated. Line balancing is also linked to workplace layout: assigning consecutive tasks to adjacent stations can shorten material and operator movement and support continuous flow. Ara et al. [4] paired heuristic balancing with a redesigned layout in a garment unit to reduce idle time and manpower requirements, although the practicality of any layout depends on physical constraints, machine positions, and material-handling needs. Line balancing should therefore be treated both as a task-allocation problem and as an operational improvement that shapes material flow.

2.3 The assembly-line balancing problem and performance measures

The assembly-line balancing problem (ALBP) consists of assigning indivisible work elements to an ordered sequence of workstations while respecting technological precedence relationships and a cycle-time limit. In the simple ALBP of type I (SALBP-I), the cycle time is given and the number of stations is minimised; in type II (SALBP-II), the number of stations is fixed and the cycle time is minimised [9], [21]. The choice of formulation depends on demand, available time, and the improvement objective. The PP bag finishing line studied here is treated as a straight-line SALBP-I, because the operations follow an established sequence and the cycle time follows from available time and target output.

Alternative configurations are compared using five indicators. The number of workstations and the production rate express resource requirement and capacity. Line efficiency is the proportion of available station-time occupied by productive work. Balance delay is the complementary proportion lost to imbalance. The smoothness index summarises differences between station workloads, with lower values indicating a more even distribution [19], [22]. Together these describe utilisation, workload distribution, and capacity; their formulas are given in Section 3.6.

2.4 Heuristic line-balancing methods

Mathematical-programming methods can yield optimal or near-optimal balances, but their formulation and solution demand considerable computational and technical resources [10]. Priority-rule heuristics are a practical alternative: they rank tasks by a decision rule and assign them to stations in rank order, subject to precedence and cycle-time feasibility. They are simple to implement and well suited to comparing alternative configurations in conventional production systems. This study applies three established heuristics that differ in their priority principle.

2.4.1 Largest Candidate Rule (LCR)

The LCR ranks tasks by processing time, from longest to shortest [13]. For each station, the longest task whose predecessors have all been assigned, and whose inclusion keeps the station load within the cycle time, is assigned first. If it is not feasible, the next eligible task is considered, and the process continues until no further task fits. The rule is simple and easy to apply when times and precedence relationships are reliable. Because it ignores the duration of successor tasks, however, it does not always give the most balanced configuration.

2.4.2 Ranked Positional Weight (RPW)

The RPW method [11] gives each task a priority value, its positional weight, equal to its own processing time plus the processing times of all direct and indirect successors. Tasks are ranked in descending order of positional weight and assigned, in that order, to the current station whenever precedence and remaining station time allow. Unlike LCR, RPW therefore reflects each task's downstream influence, which makes it useful when the precedence structure strongly shapes the allocation. It remains a priority-rule heuristic and does not guarantee a globally optimal solution.

2.4.3 Kilbridge–Wester (K&W) method

The K&W column method [12] arranges tasks in columns according to their position in the precedence diagram. Tasks with no unassigned predecessors fall in the first column, and later tasks in subsequent columns. Tasks are then assigned in column order without violating precedence or the cycle time. The method is most useful when the precedence structure is clear and can be shown as a diagram, but its performance depends on that structure and on the distribution of task times [13].

2.5 Previous empirical evidence and research gap

Recent studies, summarised in Table 1, show that heuristic balancing can yield substantial gains in garment, automotive, and assembly settings, but that the magnitude of improvement and the ranking of methods depend on the production configuration, task characteristics, and precedence structure. Following Results are as reported by the cited authors; settings and task networks differ, so values are not directly comparable.

Table 1. Summary of selected empirical studies on heuristic line balancing.

Study	Context	Method(s)	Main reported outcome
Ara et al. [4]	Garment hemming unit	LCR, RPW, K&W; layout redesign	RPW and LCR raised line efficiency from 43.70% to 79.80% and reduced workstations from 42 to 23; K&W gave a smaller improvement.
Alemayehu et al. [16]	Shirt sewing line, JP Garment, Hawassa, Ethiopia	RPW, LCR, K&W (cycle time 33 s)	From 41 stations and 67.6% efficiency to 34 stations and 85.9% (RPW), 31 and 94.2% (LCR), and 30 and 97.35% (K&W).
Çelik and Arslankaya [23]	Automotive cable supplier	RPW, K&W	Cycle time reduced from 170 s to 142.25 s; line efficiency raised from 82.36% to 98.42%.
Achmadi et al. [20]	Defence-industry assembly (56 tasks, 43 stations)	VSM + RPW	Total cycle time reduced from 5,121 s to 3,620 s (about 29%); balance delay, line efficiency, and smoothness index improved.

Study	Context	Method(s)	Main reported outcome
Bongomin et al. [24]	Trouser assembly line	RPW	RPW was effective only where resources were not constrained; complex lines with several machine types limited its usefulness.
Tesfaye et al. [3]	Apparel factory, Ethiopia	Line balancing and method study	Method-study analysis gave a larger improvement than operator reallocation alone.

Ahmed et al. [25] likewise compared LCR, K&W, and RPW in an apparel firm, aiming to reduce idle time, the number of workstations, and manpower requirements, and proposed a revised layout. Two observations follow. First, the comparative evidence on the three classical heuristics comes mainly from garment lines. Ara et al. [4] found RPW and LCR superior to K&W, whereas Alemayehu et al. [16] obtained the highest efficiency with K&W, so no method is universally best. Second, evidence from combined approaches [20] does not isolate the effect of the balancing heuristic itself. Çelik and Arslankaya [23] did not include LCR in their comparison.

In summary, to the authors' knowledge, the reviewed literature offers limited direct comparison of LCR, RPW, and K&W in PP bag finishing, an operation of cutting, stitching, counting, and packaging, and plastic-sector studies have focused on lean tools rather than on balancing [17], [18]. The present study addresses this gap by linking stopwatch-based work measurement, standard-time development, precedence analysis, and heuristic assignment in one case study at Hifam/Seid Ali PP Bag Factory, and by evaluating the three methods on identical data.

2.6 Analytical framework

The analytical framework used in this study (Table 2) links each production input or condition to an analytical step and a measurable output, from time study through to the estimation of productivity improvement.

Table 2. Analytical framework used to evaluate heuristic line balancing.

Input / condition	Analytical step	Output / performance
Observed task times	Time study and standard-time development	Standard task times
Task sequence	Precedence analysis	Feasible task relationships
Demand / operating time	Cycle-time determination	Target cycle time
Task times + precedence	LCR / RPW / K&W	Workstation assignment
Workstation assignment	Efficiency calculations	Line efficiency, balance delay, smoothness index
Balanced line	Production-rate estimation	Calculated productivity improvement

3. Methods

3.1 Research design and study setting

The study used an applied, single-case design that combined quantitative work measurement with qualitative observation of the production system. The 61 × 100 cm bag was selected because the

company identified it as a high-demand product. The focus was line 1 of the finishing section, where nine work elements (coded A–I) were identified. The unit of analysis is therefore the finishing-line task and workstation system, not the factory as a whole. The selected bag moves through cutting, transport to sewing, stitching, trimming and counting, counter checking, printing, packaging, stock, and warehousing (Fig. 1).

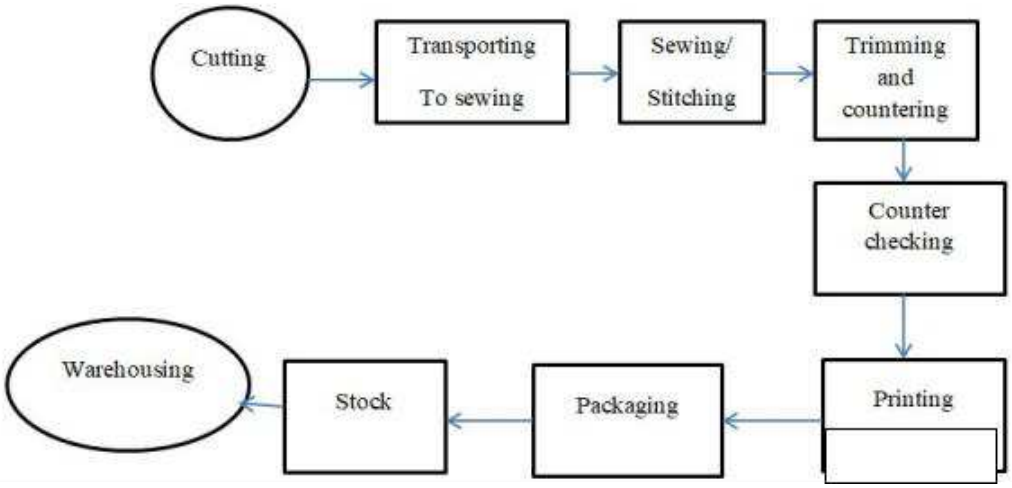


Fig. 1. Flow process of the cutting and finishing section.

3.2 Data sources and collection

Primary data were collected through direct observation of the shop floor, interviews with managers, supervisors, and workers, and stopwatch time study. Observation covered operator movement, material handling, workstation design, production flow, and the condition of the sewing and finishing area. Interviews were used to understand production activities and to identify bottlenecks and operating problems. Secondary data came from factory production records and technical documents. Analysis used flow process charts of the existing process, stopwatch, Microsoft Excel, and a calculator.

3.3 Work measurement and standard time

Stopwatch observations were used to establish representative task times. The number of observations required for a 95% confidence level and ±5% precision was determined with the standard statistical formula [26]:

$$N' = \left[\frac{40\sqrt{n\sum ft^2-(\sum ft)^2}}{\sum ft}\right]^2 \quad (1)$$

where N' is the required number of observations, n is the number of initial observations, t is the observed task time (s), and f is the frequency of each recorded time. Observed times were then averaged, multiplied by the operator's performance rating to obtain the normal time, and increased by an allowance to obtain the standard time:

$$Normal\ time = Average\ observed\ time \times Performance\ rating \quad (2)$$

$$Standard\ time = Normal\ time + Allowance \quad (3)$$

To determine the required minimum number of observation by using the following equation.

$$\left[\frac{40*\sqrt{34*1272-(206)2}}{206}\right]^2$$

N= 30.25 ☞ 30, It‟s acceptable because the minimum required sample is less than the observed time from the
Finishing section. That means, N<n or 30<34, , from the above analysis result, it can be conclude that 34
number of observation needed.
Therefore, the actual time is calculated as the average time of the actual observed time, thus.

Average actual time = $\frac{total\ time\ observed}{total\ number\ of\ observation}$

$= \frac{206\ seconds}{34}$ =6.06 seconds

The second step is to analysis the normal time for the process of fabric cutting by considering Operator's performance rating factor is 120%.
Normal time= average actual time* performance Rating factors
= 6.06 sec* 1.2
= 7.272 seconds
The final step is to calculate the standard time for Fabric Cutting process by considering standard Allowance for the operators.
Standard Time= Normal time + allowance for the workers
7.272 +20% (standard time plus 0.2 s)
7.472sec
The procedure is illustrated for fabric cutting (task A). Table 3 lists the 34 recorded times. Substituting n = 34, Σft = 206, and Σft² = 1,272 gives N′ = 30.6, or about 31 observations. Because 31 < 34, the sample is sufficient. The average observed time is 206/34 = 6.06 s. At a performance rating of 120%, the normal time is 6.06 × 1.20 = 7.272 s, and after the allowance is added the standard time used in balancing is 7.472 s. Standard times for the other eight tasks were obtained in the same way.

Table 3. *Observed task times and frequencies for fabric cutting (task A).*

t (s)	f	f·t	t²	f·t²
6	10	60	36	360
5	11	55	25	275
7	13	91	49	637
Total	**n = 34**	**Σft = 206**		**Σft² = 1,272**

3.4 Precedence analysis and cycle time

The technological sequence of the nine work elements was established from observation and discussion with supervisors and represented as a precedence diagram. The required cycle time C was calculated from the available production time and the desired output:

$$C = \frac{T_{a(\text{available time})}}{Q(\text{desired out put})} \quad (4)$$

where T_a is the available time and Q is the desired output over that time. The theoretical minimum number of workstations is the total task time divided by the cycle time, rounded up to the next integer:

$$N_{min} = \lceil \frac{\sum t_i}{C} \rceil \quad (5)$$

This value is a lower bound. A feasible solution must also satisfy the precedence constraints and keep each station's load within *C*.

3.5 Heuristic procedures

The three heuristics described in Section 2.4 were applied to the same task times, precedence relations, and cycle time. In each case tasks were prioritised according to the rule of the method and assigned sequentially to the current station while they were precedence-feasible and the accumulated station time did not exceed the cycle time; a new station was opened when no further task fit. This continued until all nine tasks were assigned. For the RPW method the positional weight of task *i* is:

$$PW_i = t_i + \sum_{j \in S_i} t_j \quad (6)$$

where S_i is the set of all direct and indirect successors of task *i*, each counted once.

3.6 Performance measures

The resulting configurations were evaluated using the following measures. Line efficiency *E* is the ratio of total task time to the available station-time, where *m* is the number of workstations:

$$E = \frac{\sum t_i}{m\,C} \times 100\% \quad (7)$$

Balance delay is the complementary proportion of capacity lost to imbalance:

$$D = 100\% - E \quad (8)$$

The smoothness index (SI) expresses variation in station workloads, with values closer to zero indicating a more even balance. For this case-study calculation, the cycle time is used as the reference load, so that each term is the idle time of station *k*:

$$SI = \sqrt{\sum_{k=1}^{m} (C - S_k)^2} \quad (9)$$

where S_k is the workload of station *k*. The production rate was estimated from the available daily production time and the cycle time, following the calculation framework of the underlying factory study.

With the assumption that the number of working hours of the production is 8 hours per day, production rate (PR)is the total working time a day by second divided to the cycle time and the number of workstations, as follows:PR= $\frac{8*60*60}{C*m}$ (10)

Where **m** is the number of work stations of the production line **c** is the cycle time

4. Results

4.1 Standard times and task precedence

Table 4 summarises the time-study results for the nine tasks. The standard times sum to 37.596 s. By total cycle time (standard time × operators assigned), upper stitching is the largest load (113.05 s), followed by fabric cutting (59.776 s).

Table 4. Standard time for each activity in the finishing section.

Task	Average time (s)	Rating (%)	Normal time (s)	Allowance (%)	Standard time (s)	No. of operators	Total cycle time (s)
Fabric cutting	6.060	120	7.272	20	7.472	8	59.776
Upper stitching	6.540	120	7.85	20	6.65	16	106.4
Upper trimming and counting	0.615	110	0.676	20	0.8765	16	14.024
Bottom stitching	1.780	120	2.136	20	2.336	16	37.376
Bottom trimming and counting	1.577	120	1.890	20	2.090	16	33.44
Bag feeding into printing machine	1.000	120	1.200	20	1.400	1	1.400
Doffing (collecting printed products)	2.238	110	2.46	20	2.66	4	10.648
Product counting	2.880	100	2.880	20	3.080	2	6.160
Packaging	10.83	100	10.83 min	20	11.03	1	11.030
Total					**37.596**		

The task precedence relations are given in Table 5 and Fig. 2. Task A must be completed before B. After B, tasks C and D can start simultaneously. Task E follows D, and F requires both C and E. After F, tasks G and H can proceed simultaneously, and packaging (I) requires both G and H. The largest individual tasks are packaging (11.030 s), fabric cutting (7.472 s), and upper stitching (6.650 s), and these strongly influence the feasible station structure.

Table 5. *Task structure, precedence relationships, and standard times for the PP bag finishing line.*

Code	Work element	Immediate predecessor(s)	Standard time (s)	Position in sequence
A	Fabric cutting	—	7.472	1
B	Upper stitching	A	6.65	2
C	Upper trimming and counting	B	0.876	3
D	Bottom stitching	B	2.336	3
E	Bottom trimming and counting	D	2.090	4
F	Bag feeding into printing machine	C, E	1.400	5
G	Collecting printed products	F	2.662	6
H	Product counting	F	3.080	6
I	Packaging	G, H	11.030	7

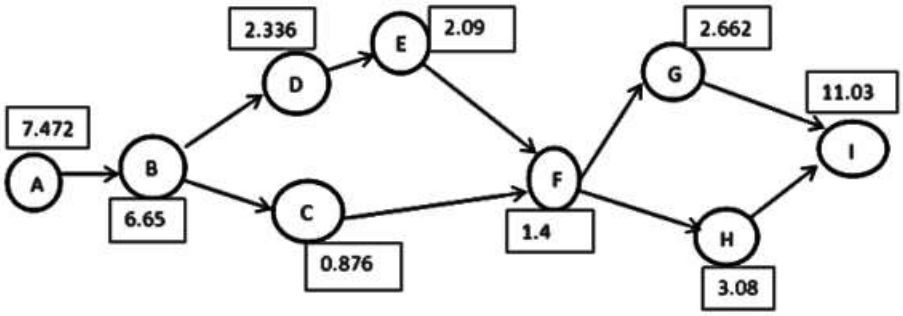


Fig. 2. *Precedence diagram of the nine finishing-line work elements (node values are standard times in seconds).*

4.2 Current performance of the finishing line

The existing finishing line used five workstations and 80 operators working an 11-hour shift (39,600 s) with 42 sewing machines. The line was not fully standardised, material moved over long distances between cutting, stitching, counting, and packaging, and workloads were uneven, with upper stitching as the main bottleneck. Limited by the bottleneck (113.05 s per bag at upper stitching), the maximum output of the finishing section is:

$$\frac{3600*11*80}{113.05} \approx 28{,}023\ pieces\ per\ shift$$

The average actual production of **(**the maximum output**)** using the highest task time is 56,046 pieces per day.however, the overall average outputs of the company is 5500 pieces per day. The theoretical output of the 80 operators at the total standard time of 38.995 s is 80 × 39,600 / 37.596 = 81,241.185 pieces per day, or 1,015.52 pieces per operator. The existing line efficiency, defined here as the ratio of actual to theoretical output, is therefore 56,046 / 81,241.185 = 68.99%. This confirms that the existing line operates below its potential and below the production plan.
The production records are consistent with this finding. In 2013 E.C. the finishing section produced Type equation here.18,490,638 bags against a target of 23,310,660 (79.3%), as noted in Section 1.

4.3 Cycle time and theoretical minimum number of workstations

With 22 hours or two 11-hrs shift (79,200 s) of available time and a desired output of 5,500 pieces, the cycle time is C = 79,200 / 5,500 = 14.4 s. The theoretical minimum number of workstations is:

$$N_{min} = \frac{37.596}{14.4} = 2.61 \approx 3 \text{ workstations}$$

Three stations is thus the minimum possible, and the question is whether a feasible three-station assignment exists under the precedence constraints.

4.4 Heuristic assignments

4.4.1 Largest Candidate Rule

Tasks were ranked by descending time: I, A, B, H, G, D, E, F, C. Task A (7.472 s) was assigned to station 1, followed by B, giving 14.122 s. Station 2 received D, E, C, F, H, and G, totalling 12.444 s. Packaging (I) cannot join this station, because 12.444 + 11.030 = 23.474 s exceeds the cycle time, so it forms station 3. Table 6 gives the result.

Table 6. *Workstation assignment obtained with the Largest Candidate Rule (C = 14.4 s).*

Workstation	Assigned tasks	Station time (s)	Idle time (s)
1	A + B	14.122	0.278
2	D + E + C + F + H + G	12.444	1.956
3	I	11.030	3.370
Total	**A–I**	**37.596**	**5.604**

4.4.2 Ranked Positional Weight

The positional weights, ranked in descending order, are given in Table 7. The assignment procedure follows the order A, B, D, E, C, F, H, G, I and yields the same three stations as LCR: A and B at station 1 (D cannot be added, because 14.122 + 2.336 = 16.458 s exceeds the cycle time), D, E, C, F, H, and G at station 2, and I at station 3. Although the priority logic differs from LCR, the precedence network and the cycle-time limit constrain the feasible allocation so tightly that the same grouping results.

Table 7. *Positional weights and ranking for the RPW method.*

Rank	Task	Successors	Positional weight (s)	Standard time (s)
1	A	B, C, D, E, F, G, H, I	37.596	7.472
2	B	C, D, E, F, G, H, I	30.124	6.650
3	D	E, F, G, H, I	22.598	2.336
4	E	F, G, H, I	20.262	2.090
5	C	F, G, H, I	19.048	0.876
6	F	G, H, I	18.172	1.400
7	H	I	14.110	3.080
8	G	I	13.692	2.662
9	I	—	11.030	11.030

4.4.3 Kilbridge–Wester method

The K&W procedure places A in column I, B in column II, C and D in column III, E in column IV, F in column V, G and H in column VI, and I in column VII. Allocating tasks in column order under the 14.4 s limit again gives the same three-station solution.

4.5 Comparison of the heuristic methods

Table 8 compares the three methods under the 14.4 s cycle time. The equality of results is a useful practical finding: for this task network, the solution is robust to the choice among the three heuristics. All three reach the theoretical minimum of three workstations, an efficiency of 87%, a balance delay of 13%, and a smoothness index of 3.9. The smoothness index follows from the station idle times (0.278, 1.956, and 3.370 s): $\sqrt{(0.278^2 + 1.956^2 + 3.370^2)} = 3.9$. The line efficiency is $E = 37.596 / (3 \times 14.4) \times 100 = 87.03\%$, and the balance delay is 13%. The company can therefore use the simplest rule for routine planning without losing calculated performance.

Table 8. *Results of the three heuristic line-balancing methods (C = 14.4 s).*

Method	Work-stations	Total task time (s)	Balance delay (%)	Line efficiency (%)	Smoothness index	Production rate (pcs/day)
LCR	3	37.596	13	87	3.9	916.67
RPW	3	37.596	13	87	3.9	916.67
K&W	3	37.596	13	87	3.9	916.67

4.6 Existing versus proposed line

Table 9 and Fig. 3 compare the existing and proposed lines. Line efficiency rises by 18 percentage points (68.99% to 87.0%), the number of workstations falls from five to three (a 40% reduction), and the calculated production rate rises from 560.113 to 916.67 pieces/day, an increase of (916.67 − 560.113) / 560.113 × 100 = 63.66%. The calculated daily output rises from 56,046 to 81,241.185 pieces, an increase of 44.95%. The total number of operators remains 80 in both cases. These changes arise from redistributing existing work content across fewer, better-defined stations, not from additional labour.

Table 9. *Existing and proposed line performance.*

Performance measure	Existing line	Proposed balanced line	Change
Total operators	80	80	0
Line efficiency	66.5%	87.0%	+20.5 percentage points
Workstations	5	3	−2 (−40%)
Calculated production rate (pcs/day)	560.113	916.67	+356.557 (+63.66%)
Daily production (pcs): actual (existing), calculated (proposed)	56,046	84,264.28	+28,218.28 (+50.35%)

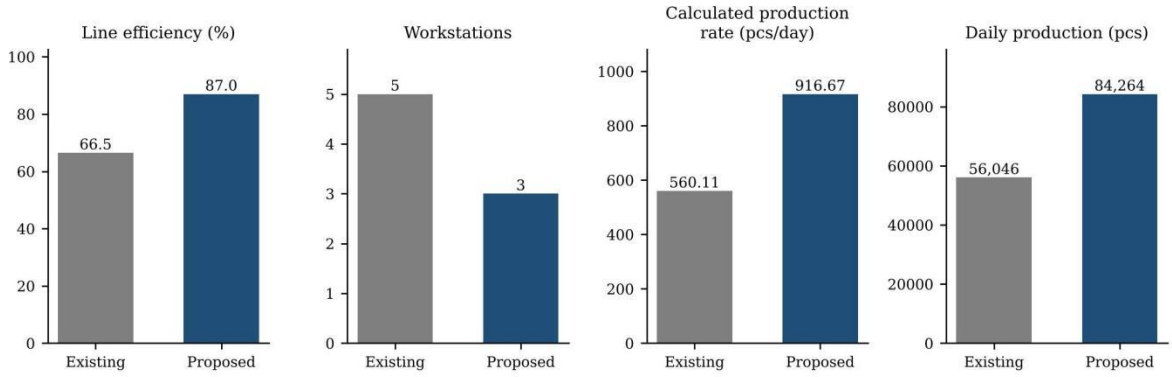


Fig. 3. *Comparison of the existing line and the proposed balanced line (proposed values are calculated).*

4.7 Proposed workstation arrangement

Table 10 shows the proposed three-station structure obtained from the balancing model.

Table 10. *Proposed workstation structure*.

Station	Combined activities	Operational interpretation
WS1	Fabric cutting + upper stitching	Combines the first two major operations within the cycle time.
WS2	Bottom stitching + trimming/counting + bag feeding + product collection + product counting	Combines several short and medium tasks to use capacity without exceeding the cycle time.
WS3	Packaging	Keeps the long packaging task as a dedicated downstream activity.

5. Discussion

5.1 Interpretation of the balancing result

Once standard times and precedence relationships were defined, the finishing line could be represented as a constrained task-assignment problem, and all three heuristics converged on the same three-station arrangement. This convergence suggests that, with a cycle time of 14.4 s, the task structure leaves little room for alternative high-quality solutions: a long packaging task (11.03 s), a strict chain from cutting to stitching, and a narrow set of short tasks that can fill station 2. The gain in efficiency from 68.99% to 87% is notable because it arises without additional operators; it comes from redistributing existing work across fewer, better-defined stations. This supports the lean view that waste arising from poor flow and uneven loading can be reduced by organisation of work rather than by added resources [5].

5.2 Bottleneck and workload distribution

Upper stitching was identified as the main bottleneck. Its standard time (6.65 s) is not the largest in isolation, but it carries the largest total load (113.05 s with 16 operators) and sits immediately after cutting, so delay there propagates downstream. Combining fabric cutting and upper stitching at station 1 uses 14.122 s of the 14.4 s cycle, a utilization of about 98%. Station 2 carries 12.444 s (1.956 s idle) and is built from several short activities that individually under-load a station but together fit the cycle, which illustrates the basic principle of balancing: small tasks can be combined to remove unnecessary station boundaries. Packaging remains a dedicated station because its time is large relative to the cycle and it requires both G and H to be complete; its 3.37 s of idle time is the largest in the line, but moving upstream tasks to it is not feasible because the load would exceed the cycle time.

5.3 Comparison with previous studies

The efficiency gain observed here (+18 percentage points) lies within the range reported elsewhere: +36.1 points in the garment hemming unit of Ara et al. [4] (43.70% to 79.80%), between +18.3 and +29.8 points in the Ethiopian sewing line of Alemayehu et al. [16] (from 67.6%), and +16.1 points in the cable-assembly line of Çelik and Arslankaya [23] (82.36% to 98.42%). The final efficiency of 87% is close to the RPW result of Alemayehu et al. (85.9%) and to the value reported by Ara et al. for RPW and LCR (79.80%).

The identical performance of the three heuristics differs from studies with larger task networks, in which the methods gave different results: RPW and LCR outperformed K&W in Ara et al. [4], whereas

K&W produced the highest efficiency in Alemayehu et al. [16]. A plausible explanation is that with only nine tasks and strong precedence constraints, the feasible solution space is small, so the priority rule matters less. This is consistent with the observation that method rankings are context-dependent and that no single heuristic is universally superior. It also indicates that, for short finishing lines like this one, a simple rule such as LCR is sufficient, which is useful for factories with limited technical capacity [7], [8].

5.4 Practical and managerial implications

The proposed solution relies mainly on work measurement, task reassignment, and workstation organisation and requires no major capital investment in machinery, which is attractive where capital is scarce but labour utilisation can be improved. Management should consider the following measures. First, standard task times should be adopted as the basis for production planning and workstation design in place of informal experience, and the balance should be reviewed whenever product models, demand, staffing, or methods change. Second, simple heuristics can serve as routine planning tools, because the three methods gave the same solution here. Third, operators should be cross-trained so that labour can be shifted between compatible tasks as demand changes. Fourth, workstations should be physically rearranged to support the proposed task grouping and reduce transport between operations. Fifth, line efficiency, idle time, production rate, and bottleneck status should be monitored after implementation, and the proposed 87% efficiency and 916.67 pieces/day treated as planning benchmarks until validated with post-implementation data.

5.5 Limitations

Several limitations should be noted. First, the improved configuration is a model-based proposal; the reported gains are calculated potential, not measured results, and a controlled before-and-after implementation is needed to establish realised effects. Second, the analysis covers a single product model (61 × 100 cm) on one finishing line, so the results should not be generalised to other models or plants without re-measurement. Third, existing efficiency (actual output relative to theoretical output of the 80 operators) and proposed efficiency (task time relative to station capacity) are defined on different bases, so the 20.5-point difference should be read as indicative rather than as a strictly like-for-like comparison. Fourth, the model reduces the line to three stations while retaining 80 operators; the practical allocation of operators and any parallel stations needed to meet demand, and the associated space and material-handling effects, were not analysed. Fifth, task times are deterministic standard times; variability, absenteeism, and machine downtime were not modelled. Finally, no cost analysis was performed.

5.6 Future research

Future work could compare heuristic balancing with mathematical programming, metaheuristics, simulation, or multi-objective optimisation [10]. Simulation would be particularly useful for evaluating stochastic task times, absenteeism, machine downtime, and variable demand. Studies could also address multi-model PP bag production, mixed-model balancing, ergonomic workload constraints, and the integration of balancing with material-handling and facility-layout optimisation, and should include post-implementation measurement to validate the calculated improvements.

6. Conclusions

This study applied three heuristic line-balancing methods to the finishing line of a PP bag factory in Ethiopia. Standard times were first developed for nine work elements and their precedence relationships defined. With a total task time of 37.596 s and a cycle time of 14.4 s, the theoretical minimum was 2.61, so three stations is the minimum feasible integer value. The Largest Candidate Rule, Ranked Positional Weight, and Kilbridge–Wester methods, applied to identical data, all produced the same three-station assignment and the same performance: 87% line efficiency, 13% balance delay, a smoothness index of 3.9, and a calculated production rate of 916.67 pieces/day. Compared with the existing five-station line, the proposed configuration raised calculated line efficiency from 68.99% to 87%, reduced the number of workstations from five to three, and increased the calculated production rate from 560.113 to 916.67 pieces/day and the calculated daily output from 56,046 to 81,241.185 pieces, while keeping 80 operators.

The main practical conclusion is that heuristic line balancing offers a simple, transparent, low-cost decision-support method for improving productivity in labour-intensive PP bag manufacturing, provided that standard times and precedence relationships are reliable. Because the improvements are calculated from a proposed model, they should be regarded as potential gains; physical implementation followed by longitudinal measurement is required before realised productivity gains can be claimed.

Declarations

Funding

The study was conducted as an institutional research activity.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

The study analysed industrial process observations, work-measurement data, and production records, and also involved interviews with factory personnel.

Consent for publication

Not applicable.

Data availability

The underlying factory data are not publicly deposited because they were obtained from an industrial case organisation. Aggregated data are included in the manuscript. Additional non-confidential information may be made available by the corresponding author, subject to permission from the case organisation.

Author contributions

Moges Mabre and Mengistu Manaye: conceptualisation, methodology, data analysis, line-balancing modelling, and manuscript preparation. Abraham Asmamaw, Husien Ababu, and Alie Wube: research

supervision and support, interpretation, review, and revision. All authors reviewed and approved the final manuscript.

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7. References

[1] K. M. N. Muthiah and S. H. Huang, "A review of literature on manufacturing systems productivity measurement and improvement," *Int. J. Ind. Syst. Eng.*, vol. 1, no. 4, pp. 461–484, 2006.

[2] S. H. Huang, J. P. Dismukes, J. Shi, Q. Su, G. Wang, M. A. Razzak, and D. E. Robinson, "Manufacturing system modeling for productivity improvement," *J. Manuf. Syst.*, vol. 21, no. 4, pp. 249–259, 2002.

[3] D. Tesfaye, F. B. Georgise, and B. Abdella, "Labour productivity improvement using line balancing and method study analysis: A case of Indochine Apparel Factory," *Ethiop. J. Eng. Technol.*, vol. 1, pp. 15–28, 2022.

[4] M. A. Ara, N. Anjum, D. Ahbab, M. T. Sidiika, and R. R. Chowdhury, "Productivity improvement of garments industry by implementing line balancing algorithms—A case study," *Eng. Rep.*, vol. 7, no. 4, Art. no. e70125, 2025, doi: 10.1002/eng2.70125.

[5] J. P. Womack and D. T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, 2nd ed. New York, NY, USA: Free Press, 2003.

[6] C. K. Chen, "Lean strategy implementation in SME manufacturing in developing countries: A systematic literature review," *Int. J. Lean Six Sigma*, advance online publication, Jan. 2026, doi: 10.1108/IJLSS-06-2025-0161.

[7] A. Alkhoraif, H. Rashid, and P. McLaughlin, "Lean implementation in small and medium enterprises: Literature review," *Oper. Res. Perspect.*, vol. 6, Art. no. 100089, 2019.

[8] Q. Hu, R. Mason, S. J. Williams, and P. Found, "Lean implementation within SMEs: A literature review," *J. Manuf. Technol. Manag.*, vol. 26, no. 7, pp. 980–1012, 2015.

[9] C. Becker and A. Scholl, "A survey on problems and methods in generalized assembly line balancing," *Eur. J. Oper. Res.*, vol. 168, no. 3, pp. 694–715, 2006, doi: 10.1016/j.ejor.2004.07.023.

[10] N. Boysen, P. Schulze, and A. Scholl, "Assembly line balancing: What happened in the last fifteen years?," *Eur. J. Oper. Res.*, vol. 301, no. 3, pp. 797–814, 2022, doi: 10.1016/j.ejor.2021.11.043.

[11] W. B. Helgeson and D. P. Birnie, "Assembly line balancing using the ranked positional weight technique," *J. Ind. Eng.*, vol. 12, no. 6, pp. 394–398, 1961.

[12] M. D. Kilbridge and L. Wester, "A heuristic method of assembly line balancing," *J. Ind. Eng.*, vol. 12, no. 4, pp. 292–298, 1961.

[13] M. P. Groover, *Automation, Production Systems, and Computer-Integrated Manufacturing*, 4th ed. Boston, MA, USA: Pearson, 2015.

[14] M. Manaye, "Line balancing techniques for productivity improvement," *Int. J. Mech. Ind. Technol.*, vol. 7, no. 1, pp. 89–104, 2019.

[15] A. Yemane, "Productivity improvement of BOB T-shirt through line balancing using control limit analysis and discrete event simulation, case study: MAA Garment and Textile Factory," *J. Optim. Ind. Eng.*, vol. 14, no. 1, pp. 19–32, 2021, doi: 10.22094/JOIE.2020.561766.1545.

[16] A. Alemayehu, F. M. Kasie, and S. Mekta, "Sewing line efficiency improvement using line balancing methods for case of JP Garment," *Ethiop. J. Eng. Technol.*, vol. 3, pp. 146–161, 2023.

[17] K. Guillen, K. Umasi, G. Quispe, and C. Raymundo, "Lean model for optimizing plastic bag production in small and medium sized companies in the plastics sector," *Int. J. Eng. Res. Technol.*, vol. 11, no. 11, pp. 1713–1734, 2018.

[18] A. M. Rodríguez Arana, H. J. Vera Espinoza, and C. M. Urbina Rivera, "Production management model to increase productivity through lean manufacturing tools as SMED, TPM and 5S in a SME in the plastic sector," in *Proc. 23rd LACCEI Int. Multi-Conf. Eng., Educ., Technol.*, 2025.

[19] M. Yin and W. Jiang, "The theory of IE assembly line balance and optimization," in *Proc. 6th Int. Conf. Machinery, Materials, Environment, Biotechnology and Computer (MMEBC 2016)*, Tianjin, China: Atlantis Press, 2016, doi: 10.2991/mmebc-16.2016.360.

[20] F. Achmadi, B. Harsanto, and A. Yunani, "Improvement of assembly manufacturing process through value stream mapping and ranked positional weight: An empirical evidence from the defense industry," *Processes*, vol. 11, no. 5, Art. no. 1334, 2023, doi: 10.3390/pr11051334.

[21] N. Boysen, M. Fliedner, and A. Scholl, "A classification of assembly line balancing problems," *Eur. J. Oper. Res.*, vol. 183, no. 2, pp. 674–693, 2007, doi: 10.1016/j.ejor.2006.10.010.

[22] R. Ginting and William, "Assembly line balancing with method ranking positional weight (case study: XYZ Company)," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1003, no. 1, Art. no. 012032, Dec. 2020, doi: 10.1088/1757-899X/1003/1/012032.

[23] M. T. Çelik and S. Arslankaya, "Solution of the assembly line balancing problem using the rank positional weight method and Kilbridge and Wester heuristics method: An application in the cable industry," *J. Eng. Res.*, vol. 11, no. 3, pp. 182–191, 2023, doi: 10.1016/j.jer.2023.100082.

[24] O. Bongomin, J. I. Mwasiagi, E. O. Nganyi, and I. Nibikora, "Improvement of garment assembly line efficiency using line balancing technique," *Eng. Rep.*, vol. 2, no. 4, Art. no. e12157, 2020, doi: 10.1002/eng2.12157.

[25] T. Ahmed *et al.*, "Application of line balancing heuristics for achieving an effective layout: A case study," *Int. J. Res. Ind. Eng.*, vol. 9, no. 2, pp. 114–129, 2020.

[26] A. Freivalds, *Niebel's Methods, Standards, and Work Design*, 13th ed. New York, NY, USA: McGraw-Hill, 2014.