ADMI JUIT Jurnal Ilmiah Teknik
JUIT Vol 5 No. 2 | May 2026 | ISSN: 2828-6936 (Print), ISSN: 2828-6901 (online), Page. 504-524

Analysis and Improvement of Rubber Roll Production Line Balancing Using Ranked Positional Weight (RPW) and Region Approach Methods at CV. ABC

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Article History
Received : July 02, 2026
Revised : July 14, 2026
Accepted : July 15, 2026
Published : July 15, 2026

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Cite This Article *[APA Style]*:
Rahman, F., & Widiasih, W. (2026). Analysis and Improvement of Rubber Roll Production Line Balancing Using Ranked Positional Weight (RPW) and Region Approach Methods at CV. ABC. *Jurnal Ilmiah Teknik*, *5*(2), 504–524.

DOI:
https://doi.org/10.56127/juit.v5i2.2901

Abstract: The rubber roll production line at CV. ABC exhibited considerable workload imbalance among workstations, particularly at the steam and turning processes. Differences in processing times resulted in potential bottlenecks, high balance delay, and inefficient utilization of available production-line capacity. **Objective:** This study aims to analyze the existing rubber roll production-line balance and compare the Ranked Positional Weight (RPW) and Region Approach methods to identify a workstation configuration with improved line utilization and more uniform workload distribution. **Methodology:** A quantitative engineering case-study approach was applied. Primary data were collected through direct observation, interviews, documentation, and stopwatch time study, while secondary data were obtained from company production records and relevant literature. Processing-time data, precedence relationships, performance ratings, and allowances were analyzed to determine work-element times and production-line characteristics. The existing configuration was evaluated using line efficiency, balance delay, idle time, and smoothness index. Work elements were subsequently reallocated using RPW and the Region Approach, and the resulting production-line performances were compared. **Findings:** The existing production line consisted of six workstations with a line efficiency of 52%, a balance delay of 48%, and a smoothness index of 214.04. Both RPW and the Region Approach reduced the number of workstations to five and increased line efficiency to 70%, while balance delay decreased to 30%. However, RPW produced a smoothness index of 117.4179, considerably lower than the 223.29228 obtained using the Region Approach. The RPW configuration also resulted in a total idle time of 204.38 min, indicating improved utilization of available workstation capacity. **Implications:** The findings provide an engineering basis for reorganizing work-element allocation in rubber roll production. The proposed RPW configuration can support more uniform workstation loading and improve production-flow efficiency, particularly in manufacturing processes with substantial variation in processing times. **Originality:** This study provides a direct comparison between cumulative positional-weight allocation and precedence-region grouping under the same rubber roll production conditions. The results demonstrate that identical line efficiency and balance delay do not necessarily indicate equivalent workload uniformity, highlighting the importance of smoothness index as a complementary criterion for selecting a line-balancing configuration.

Keywords: line balancing; Ranked Positional Weight; Region Approach; line efficiency; smoothness index.

INTRODUCTION

The increasing competitiveness of the manufacturing industry requires production systems to maintain stable process flows, achieve output targets, and utilize working time efficiently. Increases in cycle time and waiting activities can extend production completion times and reduce a production system's ability to achieve its operational targets (Dwinanta & Widiasih, 2025). Uneven workloads among workstations may also cause certain operators or facilities to experience excessive idle time, while other workstations are subjected to higher processing loads and potentially become production bottlenecks. These technical conditions were identified in the rubber roll production process at CV. ABC, which consists of six main workstations: smoothing, adhesive application, rubber coating, steam processing, turning, and finishing. Field measurements showed processing times of 34.02, 57.21, 86.55, 120.88, 134.44, and 34.72 min for the respective workstations. Therefore, the processing-time range between the shortest and longest workstation was 100.42 min. The turning process had the longest processing time of 134.44 min, followed by the steam process at 120.88 min, whereas smoothing and finishing required only 34.02 and 34.72 min, respectively. This considerable dispersion in processing times indicates that workloads are not uniformly distributed along the production line and technically suggests potential restrictions on continuous product flow at workstations with longer processing durations.

The technical imbalance of the production line is also reflected in the company's production fulfilment performance from August 2025 to January 2026. During this period, total demand reached 590 units, whereas the company completed only 514 units, resulting in a production shortfall of 76 units and a demand fulfilment rate of 87.12%. Field observations indicated that the existing allocation of work elements had not been systematically designed based on standard time, precedence relationships, and cycle-time evaluation. Structured work-time measurement is essential because work-element times form the quantitative basis for determining workstation loads and production-line configurations (Ponda et al., 2019). Previous manufacturing applications have demonstrated that unbalanced work allocation can be associated with low line efficiency and high idle time, making work-element reallocation an important component of production-line performance evaluation (Fauzi & Saifuddin Z.S, 2025). Although the difference between production demand and actual output at CV. ABC cannot be attributed exclusively to a single factor, the combination of high processing-time variation, the concentration of processing duration at the steam and turning workstations, and the absence of an engineering-based work allocation procedure indicates the need for a systematic line-balancing analysis. Therefore, the existing production line must be quantitatively evaluated using line efficiency, balance delay, idle time, and smoothness index to determine whether work-element reconfiguration can provide a more uniform distribution of workstation times.

Studies on production line balancing have extensively applied heuristic approaches because these methods can allocate work elements while considering task duration and precedence relationships. The Ranked Positional Weight (RPW) method determines activity priorities based on positional weights calculated from the processing time of a work element and all of its successors in the precedence diagram (Ponda et al., 2019). The application of RPW to a production process at PT XYZ demonstrated that positional-weight ranking could be used to rearrange work allocation and achieve a line efficiency of 86.45% (Sidiq & Darajatun, 2023). Christata similarly reported that RPW-based reconfiguration produced a line efficiency of 96% and a balance delay of 4% in an electronics manufacturing case (Christata et al., 2023). In the production of rear brake arms, RPW was applied to reduce workstation imbalance by reallocating work elements according to their positional priorities (Novianti & Herwanto, 2023). Comparative investigations have also evaluated RPW alongside the Largest Candidate Rule and J-Wagon methods based on differences in workstation configuration and resulting line efficiency (Pulansari & Nugraha, 2023). These findings indicate that RPW remains a relevant heuristic approach for production systems in which precedence constraints can be clearly defined.

Another heuristic approach allocates work elements according to their positions within the precedence diagram. The Region Approach divides a precedence diagram into regions and allocates activities by considering the sequence of operational relationships and the established cycle-time limit (Tjioewinata & Saifuddin, 2022). A comparison of five line-balancing methods in jacket production demonstrated that different priority rules could generate different workstation configurations and efficiency levels even when the same set of work elements was evaluated (Kusuma & Purnomo, 2024). A study in the traditional cap manufacturing industry also compared the Region Approach and RPW and demonstrated that the selected allocation mechanism affected line efficiency, balance delay, and production-line idle time (Zahra & Rusindiyanto, 2025). Previous RPW studies have generally emphasized the reduction of idle time through activity prioritization based on positional weights, whereas the Region Approach maintains the relative positions of work elements according to precedence structures. Purnamasari and Cahyana demonstrated that the Ranked Position Weight method could determine workstation groups based on task priority sequences (Purnamasari & Cahyana, 2015). However, the cumulative-weight priority mechanism of RPW and the precedence-region allocation mechanism do not necessarily produce identical performance for production systems with different process characteristics. Consequently, the two approaches should be compared using identical work-element times, cycle-time limits, and precedence constraints so that differences in line performance can be attributed to their respective work-allocation mechanisms.

The development of line-balancing research has also progressed toward integrated work measurement, simulation, and computational optimization methods. Breznik (Breznik et al., 2023) integrated Methods-Time Measurement with simulation modelling to evaluate assembly-line configurations using standard time as a model input. Stopwatch time study and Arena simulation were applied by Teshome to evaluate a garment production line, where the proposed scenario increased line efficiency from 39.06% to 55.64% while simultaneously improving production output (Teshome et al., 2024). For U-shaped production lines, inter-task transfer times have also been incorporated as constraints in line-balancing optimization (Kuo et al., 2023). More advanced computational approaches have employed genetic algorithms to improve production-line balance using workstation performance-based objective functions (Sutomo et al., 2022). Genetic algorithms have also been developed for assembly lines involving human–robot collaboration and operator heterogeneity (Nourmohammadi et al., 2022), whereas Jia applied deep reinforcement learning to optimize line efficiency and smoothness in two-sided assembly lines (Jia et al., 2023). Recent developments include modified genetic algorithms for resource reconfiguration in robotic assembly lines (Albus et al., 2025) and multi-objective genetic algorithms that account for uncertainty in robotic task times (Zacharia & Nearchou, 2025).

The comprehensive review by Battaïa and Dolgui further demonstrated that line-balancing research is increasingly integrated with process planning, workforce planning, and resource scheduling (Battaïa & Dolgui, 2022). However, the reviewed literature indicates that these advanced optimization approaches are predominantly designed for assembly lines, mixed-model lines, or robotic manufacturing systems that require relatively complex mathematical formulations and computational procedures. Technical evidence concerning a direct comparison between RPW and the Region Approach in rubber roll production, which involves high processing-time variation and a combination of manual and machine-based operations, remains limited. In particular, it remains technically unclear whether the cumulative positional-weight priority used by RPW can produce a more uniform distribution of workstation times than the regional allocation mechanism when both methods are implemented under identical cycle-time and precedence constraints. This unresolved issue constitutes the engineering research gap addressed in this study.

Based on the identified technical problems and engineering research gap, this study aims to analyze the production-line balance of the rubber roll manufacturing process at CV. ABC and evaluate two alternative work-element allocation methods using Ranked Positional Weight and the Region Approach. Operationally, work-element times are measured using a stopwatch time study, followed by data adequacy and uniformity evaluations and the determination of normal and standard times as analytical parameters. The technical relationships among production activities are represented through a precedence diagram to define the operational sequence and precedence constraints of each work element. The existing production-line configuration is then evaluated based on cycle time, number of workstations, line efficiency, balance delay, total idle time, and smoothness index. Subsequently, the work elements are reallocated using RPW and the Region Approach while maintaining identical cycle-time limits and precedence constraints. The resulting configurations are quantitatively compared to identify the allocation method that provides higher line efficiency, lower idle time, and lower variation in processing times among workstations.

The technical contribution of this study is a comparative evaluation of two work-element allocation mechanisms applied to a rubber roll production process characterized by substantial variation in operational processing times. RPW represents a priority mechanism based on the cumulative processing load of an activity and its successors, whereas the Region Approach represents an allocation mechanism based on the position of activities within a precedence diagram. The engineering hypothesis of this study is that work-element allocation using RPW can produce a lower smoothness index and a more uniform distribution of workstation times than the Region Approach when both methods are evaluated under identical cycle-time and precedence constraints. This assumption is based on the positional-weight mechanism, which assigns higher priority to work elements with greater cumulative successor loads and may therefore reduce workload accumulation toward the downstream section of the production line. The quantitative comparison of the two methods is expected to provide an engineering basis for selecting a proposed workstation configuration based on line efficiency, balance delay, idle time, and smoothness index, while providing a transparent and reproducible line-balancing approach for manufacturing processes that combine manual and machine-based operations.

RESEARCH METHOD

The unit of analysis in this study was the rubber roll production line at CV. ABC. The analysis focused on the distribution of processing workloads among workstations and the balance of the production line. The investigated production process consisted of sequential activities with technical relationships between preceding and succeeding work elements. The main parameters evaluated in this study included the observed processing time of each work element, cycle time, precedence relationships, workstation allocation, line efficiency, balance delay, idle time, and smoothness index. The analysis was conducted on the existing production-line configuration and on the proposed workstation configurations generated using the Ranked Positional Weight (RPW) and Region Approach methods.

This study employed a quantitative engineering case-study design based on direct field observation and analytical evaluation of the existing production system. The research focused on analyzing and improving the balance of the rubber roll production line to increase production-flow efficiency and reduce workload imbalance among workstations. The research began with problem identification in the existing production line, followed by direct observations and production-data collection. The collected processing-time data were subsequently evaluated using data adequacy and data uniformity tests to ensure that the observation data were sufficient and consistent for further analysis. The average observed time, normal time, and standard time were then determined as the basic parameters for production-line balancing analysis.

The study used primary and secondary data. Primary data were obtained through direct field observations, interviews with operators and company personnel, and work-element processing-time measurements using the stopwatch time study method. The primary data consisted of cycle-time information, observed processing times for each work element, precedence relationships, performance ratings, allowances, and the existing allocation of work elements among workstations. Secondary data were obtained from company documents and relevant scientific literature. The company data included the production-process flow, production-demand data, and the existing production layout. Scientific literature related to line balancing, RPW, and the Region Approach was used to support the work-element allocation procedures and production-line performance evaluation.

Data collection was conducted directly in the rubber roll production area at CV. ABC. Field observations were used to identify the actual production sequence, individual work elements, workstation arrangement, and precedence relationships among production activities. Interviews with operators and company personnel were conducted to obtain supporting information concerning the production process and the existing distribution of work among workstations. The processing time of each work element was measured using a stopwatch time study during actual production operations. Repeated observations were conducted, and the recorded processing times were used to determine the average observed time. The average observed time was calculated using Equation (1).

$$\bar{t} = \frac{\sum_{i=1}^{N} t_i}{N}$$

where $\bar{t}$ is the average observed time, t_i is the processing time recorded during observation i, and N is the number of observations.

The collected processing-time data were evaluated using data adequacy and data uniformity tests. The data adequacy test was conducted to determine whether the number of observations was sufficient to represent the processing-time characteristics of each work element. The data uniformity test was subsequently used to determine whether the observed processing times remained within acceptable statistical limits. Only processing-time data that satisfied the adequacy and uniformity requirements were used for subsequent calculations.

The average observed time was converted into normal time by considering the operator performance-rating factor. Normal time was calculated using Equation (2).

$$NT = \bar{t} \times PR$$

where NT is the normal time and PR is the performance-rating factor.

The standard time was then determined by incorporating the allowance factor into the normal time. Standard time was calculated using Equation (3).

$$T_s = \frac{NT}{1-A}$$

where T_s is the standard time and A is the allowance expressed as a decimal fraction. The standard time of each work element was used as the time parameter in the production-line balancing analysis.

The technical sequence and relationships among work elements were identified based on direct observations of the rubber roll production process. Each work element was arranged according to its preceding and succeeding activities and subsequently represented in a precedence diagram. The precedence diagram described the sequence and dependencies among production activities and was used as the primary constraint for work-element allocation using both RPW and the Region Approach.

The analysis of the existing production-line condition was performed by determining the cycle time, identifying the existing number of workstations, and evaluating the performance of the production line. Cycle time was used as the maximum processing-time limit for each workstation and was calculated using Equation (4).

$$CT = \frac{T}{Q}$$

where CT is the cycle time, T is the available production time, and Q is the required production output.

The idle time of each workstation was determined from the difference between the cycle time and the total processing time assigned to the workstation. Idle time was calculated using Equation (5).

$$IT_i = CT - W_i$$

where IT_i is the idle time of workstation I and $W_i$is the total processing time assigned to workstation i.

Line efficiency was used to evaluate the proportion of available workstation time utilized for production activities. Line efficiency was calculated using Equation (6).

$$LE = \frac{\sum_{i=1}^{n} W_i}{n \times CT} \times 100$$

where LE is the line efficiency and n is the number of workstations.

Balance delay represents the proportion of available production-line time that is not effectively utilized for processing activities. Balance delay was calculated using Equation (7).

$$BD = 100\ \% \text{ - LE}$$

where BD is the balance delay.

The smoothness index was used to evaluate the uniformity of workload distribution among workstations. The smoothness index was calculated using Equation (8).

$$SI = \sqrt{\sum_{i=1}^{n} (W_{max} - W_i)^2}$$

where SI is the smoothness index, W_{max} is the highest workstation processing time, and W_i is the processing time of workstation i. A lower smoothness index indicates a more uniform distribution of processing loads among workstations.

After the existing production-line condition was evaluated, the work elements were reallocated using the Ranked Positional Weight method. RPW is a line-balancing method that determines work-element allocation priorities based on the positional weight of each activity. The positional weight consists of the processing time of a work element and the processing times of all succeeding work elements in the precedence diagram (Poncotoyo et al., 2022). The relative position of each activity in the production sequence is used to establish its allocation priority (Sidiq & Darajatun, 2023). The method is intended to improve workload distribution among workstations and reduce idle time (Fauzi & Saifuddin Z.S, 2025).

The positional weight of each work element was calculated using Equation (9).

$$PW_i = t_i + \sum_{j \in S_i} t_j$$

where PW_i is the positional weight of work element i, t_i is the processing time of work element i, and $S_i$is the set of succeeding work elements associated with activity i.

The RPW analysis was conducted by first constructing a precedence diagram based on the actual sequence of the rubber roll production process. The positional weight of each work element was then calculated by summing the processing time of the respective work element and all of its succeeding activities. The work elements were ranked from the highest to the lowest positional weight. Work elements were subsequently allocated to workstations according to their rankings while considering the precedence relationships and cycle-time limit. The proposed RPW configuration was then evaluated using line efficiency, balance delay, idle time, and smoothness index.

The Region Approach was also applied to redesign the rubber roll production line. This method groups work elements into several regions according to their positions and relationships in the precedence diagram. The structure of the precedence relationships is used to facilitate the systematic grouping and allocation of production activities to obtain a more balanced distribution of workstation loads (Kusuma & Purnomo, 2024). The Region Approach allocates work elements by considering the relationships among activities and the available cycle time at each workstation (Tjioewinata & Saifuddin, 2022).

The Region Approach analysis began with the construction of the precedence diagram based on the actual production sequence. The work elements were subsequently grouped into regions according to their precedence relationships and relative positions within the diagram. Each region represented work elements with direct or sequential relationships in the production process (Zahra & Rusindiyanto, 2025). Cycle time was then established as the maximum processing-time limit for each workstation. Work elements were allocated to workstations according to their respective regions while ensuring that the total workstation time did not exceed the cycle-time limit. The resulting production-line configuration was evaluated using line efficiency, balance delay, idle time, and smoothness index.

The production-line performance obtained using RPW and the Region Approach was compared with the existing production-line condition. The comparative analysis was based on line efficiency, balance delay, smoothness index, idle time, and the number of workstations generated by each configuration. The method that produced the highest line efficiency and the lowest production-line imbalance was selected as the preferred method for improving the rubber roll production line at CV. ABC.

RESULT

Data collection was conducted on the rubber roll production process at CV. ABC through direct observation, interviews, documentation, and processing-time measurement using a stopwatch time study. The collected data included the processing time of each production activity, the sequence of production operations, and the precedence relationships among work elements. Based on field observations, the production process consisted of six main workstations: smoothing, adhesive application, rubber coating, steam processing, turning, and finishing. The processing times of the existing workstations are presented in Table 1.

Table 1. Processing Time of the Rubber Roll Production Process

No.	Workstation	Processing Time (min)
1	Smoothing	34.02

2	Adhesive application	57.21
3	Rubber coating	86.55
4	Steam processing	120.88
5	Turning	134.44
6	Finishing	34.72

The processing-time data show a considerable difference among the six workstations. The turning workstation had the longest processing time of 134.44 min, followed by steam processing at 120.88 min. Rubber coating required 86.55 min, whereas adhesive application required 57.21 min. The lowest processing times were recorded at the smoothing and finishing workstations, with values of 34.02 and 34.72 min, respectively. Three dominant patterns were identified from these data. First, the processing load increased progressively from smoothing to turning. Second, steam processing and turning formed the two highest-load workstations in the production sequence. Third, the processing time decreased sharply at the finishing workstation after reaching the maximum value at the turning process. These processing-time differences indicate an uneven distribution of workload among workstations and identify the steam and turning operations as the dominant high-load processes with potential bottleneck characteristics.

The performance of the existing production line was subsequently evaluated using line efficiency, balance delay, idle time, and smoothness index. Based on the initial production-line calculation, the line efficiency was 52%, while the balance delay was 48%. The smoothness index of the existing configuration was 214.04. The performance indicators of the initial production-line condition are summarized in Table 2.

Table 2. Performance of the Existing Production-Line Configuration

Performance Indicator	Existing Condition
Number of workstations	6
Line efficiency (%)	52
Balance delay (%)	48
Smoothness index	214.04

The initial production-line configuration showed that only 52% of the available line capacity was effectively utilized, whereas the remaining 48% was represented by balance delay. The smoothness index of 214.04 indicates a high variation in workload distribution among the existing workstations. Three main technical characteristics were observed. First, the line efficiency remained relatively low compared with the proportion of unutilized production-line time. Second, the balance delay was close to half of the available production-line capacity. Third, the high smoothness index was consistent with the large differences in workstation processing times shown in Table 1. These results demonstrate that the existing production-line configuration had not achieved a balanced distribution of processing loads and therefore required work-element reallocation.

The first production-line improvement was performed using the Ranked Positional Weight method. The positional weight of each work element was determined from the precedence diagram, after which the elements were ranked from the highest to the lowest positional weight. The ranked work elements were then allocated to new workstations while considering the cycle-time limit. The resulting RPW workstation allocation is shown in Table 3.

Table 3. Workstation Allocation Using the Ranked Positional Weight Method

Workstation	Work Elements	Workstation Time (min)
1	O-1, O-4, O-2, O-3	91.23
2	O-5, O-6	97.10
3	O-7, O-8	110.33
4	O-9	134.44
5	O-10, O-11	34.72

The RPW method reduced the production-line configuration from six to five workstations. Workstation 4 had the highest processing time of 134.44 min, while Workstation 5 had the lowest processing time of 34.72 min. The processing times of Workstations 1, 2, and 3 were 91.23, 97.10, and 110.33 min, respectively. A progressive increase in processing time was observed from Workstation 1 to Workstation 4, followed by a substantial decrease at Workstation 5. The corresponding idle times for the RPW configuration are presented in Table 4.

Table 4. Idle Time of the Ranked Positional Weight Configuration

Workstation	Idle Time (min)
1	43.21
2	37.34
3	24.11
4	0.00
5	99.72
Total	**204.38**

The total idle time of the RPW configuration was 204.38 min. Workstation 4 had no idle time because its workstation time reached the cycle-time limit. In contrast, Workstation 5 had the highest idle time of 99.72 min. Idle time decreased from 43.21 min at Workstation 1 to 24.11 min at Workstation 3 as the allocated processing load increased. Three dominant trends were observed in the RPW results. First, the number of workstations was reduced by one workstation. Second, the middle workstations showed a more gradual distribution of processing times. Third, the maximum-load workstation was fully utilized, although a relatively high idle time remained at the final workstation. Overall, the RPW configuration produced a more balanced distribution of work elements than the existing production-line arrangement.

The quantitative evaluation showed that the RPW method increased line efficiency from 52% to 70%. Balance delay decreased from 48% to 30%, while the smoothness index decreased from 214.04 to 117.4179. The reduction in the smoothness index indicates that the variation in workstation processing loads was lower after RPW-based reallocation. Simultaneously, the improvement in line efficiency and reduction in balance delay demonstrate greater utilization of the available production-line capacity. These results identify the positional-weight allocation mechanism as an effective approach for redistributing work elements within the investigated rubber roll production line.

The second production-line improvement was performed using the Region Approach. The work elements were grouped according to their relationships and positions in the precedence diagram. The resulting region classification is presented in Table 5.

Table 5. Work-Element Grouping Using the Region Approach

Region	Operation Ranking
1	O-1
2	O-2, O-4, O-3
3	O-5
4	O-7, O-6, O-8
5	O-9
6	O-10, O-11

The Region Approach produced six precedence-based regions. Regions 1, 3, and 5 each contained a single work element. Region 2 contained O-2, O-4, and O-3, while Region 4 contained O-7, O-6, and O-8. The final region consisted of O-10 and O-11. The grouping pattern demonstrates that the Region Approach retained the relationship and relative position of work elements within the precedence structure. The proposed allocation reduced the number of workstations from six to five and produced a line efficiency of 70% and a balance delay of 30%. However, the resulting smoothness index was 223.29228, which was higher than both the RPW configuration and the initial production-line smoothness index.

The comparative performance of the existing configuration, RPW, and the Region Approach is presented in Table 6.

Table 6. Comparison of Production-Line Performance

Indicator	Existing Condition	RPW	Region Approach
Number of workstations	6	5	5
Line efficiency (%)	52	70	70
Balance delay (%)	48	30	30
Smoothness index	214.04	117.4179	223.29228

The comparative results reveal four dominant technical findings. First, both RPW and the Region Approach reduced the number of workstations from six to five. Second, both methods increased line efficiency from 52% to 70%. Third, balance delay decreased from 48% to 30% for both proposed configurations. Fourth, a substantial difference was observed in the smoothness index. RPW reduced the smoothness index from 214.04 to 117.4179, whereas the Region Approach produced a smoothness index of 223.29228.

The identical values of line efficiency and balance delay indicate that both methods provided similar overall utilization of the production-line capacity. However, the smoothness-index results distinguish the workload-distribution characteristics of the two methods. The lower smoothness index obtained using RPW indicates a more uniform distribution of processing loads among workstations. In contrast, the higher smoothness index of the Region Approach indicates greater variation in workstation times despite the improvement in line efficiency and balance delay. Therefore, based on the reported performance indicators, RPW provided the best production-line balancing performance because it combined a reduced number of workstations, higher line efficiency, lower balance delay, and the lowest smoothness index among the evaluated configurations.

DISCUSSION

The results indicate that the rubber roll production line at CV. ABC experienced a substantial workload imbalance before line-balancing improvement was conducted. The existing configuration was characterized by low line efficiency, high balance delay, and a relatively high smoothness index, indicating that the processing load was not uniformly distributed among workstations. This imbalance was particularly associated with the steam and turning processes, which required considerably longer processing times than the other production stages. The concentration of high processing loads at these workstations created potential bottlenecks and increased unused production capacity at lower-load workstations. Consequently, the existing production-line configuration was unable to utilize the available workstation time efficiently.

From an engineering perspective, the imbalance occurred because the processing-time requirements of the workstations were substantially different. When a high-load workstation requires a longer processing duration than preceding operations, work elements may accumulate before the constrained workstation because upstream stations complete their activities at a higher processing rate. Conversely, workstations with shorter processing times may experience greater idle capacity while waiting for work from the preceding process. This difference in workstation processing capacity creates an uneven production-flow pattern and reduces overall line utilization. In the present production system, the high processing times of the steam and turning operations therefore represented the dominant constraints affecting production-line balance.

The application of the Ranked Positional Weight method substantially improved production-line performance. RPW reduced the number of workstations from six to five while increasing line efficiency and reducing balance delay. This improvement indicates that several work elements could be regrouped into a smaller number of workstations without exceeding the established cycle-time constraint. The redistribution of work elements increased the utilization of available workstation time and reduced the proportion of unproductive capacity within the production line. Therefore, the improvement produced by RPW was primarily associated with a more effective allocation of production activities rather than a reduction in the total processing requirements of the product.

The reduction in the smoothness index after the application of RPW provides further evidence of improved workload distribution. A lower smoothness index indicates that the difference in processing loads among workstations was reduced compared with the existing production-line configuration. The total idle time of the RPW configuration was also reduced to 204.38 min, demonstrating that a larger proportion of available workstation capacity could be used for productive activities. These results confirm that RPW was able to reduce workstation-load variation and improve production-flow balance. The resulting configuration may consequently reduce excessive waiting between production activities and support a more continuous flow of rubber roll products through the production line.

The technical performance of RPW can be explained by its positional-weight allocation mechanism. The method determines the priority of each work element by considering not only its individual processing time but also the processing times of all subsequent activities in the precedence diagram. Work elements associated with greater cumulative downstream workloads therefore receive higher allocation priorities. This mechanism reduces the possibility that several high-load activities become concentrated in the later sections of the production line. In a production process characterized by substantial variation in work-element processing times, cumulative positional weighting provides a technical advantage because workstation allocation considers the future processing load associated with each activity.

The findings are consistent with the application of RPW reported by (Ponda et al., 2019), in which work-element allocation based on positional weight was used to improve production-line balance in a manufacturing process. Sidiq and Darajatun also demonstrated that activity ranking according to precedence position and cumulative task weight can support the redistribution of workstation loads (Sidiq & Darajatun, 2023). The present results further support (Fauzi & Saifuddin Z.S, 2025), who reported that RPW can improve production-line utilization and reduce idle time by reorganizing work activities among workstations. These similarities indicate that the effectiveness of RPW is closely associated with its ability to integrate processing-time information and precedence relationships into the work-element allocation procedure.

The Region Approach also improved production-line performance compared with the existing configuration. Grouping work elements according to their precedence relationships reduced the number of workstations and increased overall line utilization. This finding is consistent with (Tjioewinata & Saifuddin, 2022), who demonstrated that precedence-based regional grouping can facilitate systematic work-element allocation. Kusuma and Purnomo similarly showed that differences in line-balancing allocation rules can generate different workstation-load configurations even when identical production activities are evaluated (Kusuma & Purnomo, 2024). Therefore, the improvement obtained using the Region Approach confirms that reorganizing work elements according to the precedence structure can provide better production-line performance than maintaining the existing workstation arrangement.

However, the Region Approach generated a higher smoothness index than RPW. Although both methods produced the same line efficiency and balance delay, the difference in smoothness index demonstrates that their workstation-load distributions were not identical. RPW produced a smoothness index of 117.4179, whereas the Region Approach produced a value of 223.29228. Therefore, the principal technical advantage of RPW was not higher overall line efficiency than the Region Approach, but a more uniform distribution of processing loads among the resulting workstations. This distinction is important because identical line efficiency values may still represent substantially different workload distributions.

The difference between the two methods can be associated with their allocation mechanisms. The Region Approach primarily groups work elements according to their relative positions and relationships within the precedence diagram. This mechanism facilitates sequential work allocation but does not explicitly prioritize work elements according to their cumulative downstream processing loads. In contrast, RPW incorporates the processing time of successor activities into the positional-weight calculation. For the rubber roll production line, which has considerable differences in processing times among production activities, the cumulative-load mechanism of RPW provided a more appropriate basis for distributing work elements. This finding supports the results reported by Zahra and Rusindiyanto which indicate that different line-balancing approaches may produce different levels of workload balance depending on the characteristics of the production process (Zahra & Rusindiyanto, 2025).

From an engineering optimization perspective, the results demonstrate that line efficiency and balance delay should not be used as the only criteria for selecting a production-line configuration. In this study, RPW and the Region Approach produced identical line efficiency and balance delay, yet substantially different smoothness-index values. Therefore, smoothness index provides an important complementary indicator for evaluating the uniformity of workstation workloads. The combination of these performance indicators allows engineers to distinguish between configurations that provide similar overall capacity utilization but different distributions of processing loads.

The proposed RPW configuration can be used as an engineering basis for reorganizing work-element assignments at CV. ABC. The company can allocate production activities according to the proposed workstation groups while maintaining the established precedence relationships and cycle-time constraints. Particular attention should remain focused on the steam and turning processes because these operations represent the highest processing loads in the production sequence. Periodic processing-time measurements should also be conducted to determine whether changes in operator performance, production methods, or equipment conditions affect the standard time of each work element. After implementation, workstation utilization, idle time, work-in-process accumulation, and actual production output should be monitored to validate the operational effectiveness of the proposed production-line configuration.

Overall, the application of line balancing improved the performance of the rubber roll production process and reduced inefficient use of available production time. Among the two heuristic approaches evaluated, RPW provided the best workload-distribution performance because it combined a reduced number of workstations, increased line efficiency, reduced balance delay, and the lowest smoothness index. Therefore, RPW is considered the preferred line-balancing method for the investigated production process. However, this conclusion is limited to the methods and operating conditions evaluated in the present study and does not represent proof of a global mathematical optimum.

CONCLUSION

The main engineering finding of this study is that the rubber roll production line at CV. ABC was characterized by an uneven distribution of workstation loads, particularly at the steam and turning processes, which created potential bottlenecks and reduced the effective utilization of production-line capacity. The application of line-balancing methods improved the production configuration by reducing the number of workstations from six to five and increasing line efficiency from 52% to 70%, while balance delay decreased from 48% to 30%. Among the evaluated methods, Ranked Positional Weight produced the lowest smoothness index, decreasing from 214.04 in the existing configuration to 117.4179. These results indicate that RPW generated a more uniform distribution of workstation processing loads than the Region Approach and was therefore identified as the preferred line-balancing alternative for the investigated rubber roll production process.

The scientific and engineering contribution of this study lies in demonstrating that production-line configurations with identical line efficiency and balance delay may still exhibit substantially different levels of workload uniformity. The comparison between

RPW and the Region Approach shows that the smoothness index provides an important complementary performance indicator for distinguishing workstation configurations with similar overall capacity utilization. From an engineering-method perspective, the study provides a measurable line-balancing procedure that integrates stopwatch time study, precedence relationships, positional-weight analysis, and quantitative production-line performance indicators. The findings also indicate that cumulative successor workload, as considered in RPW, can provide a more suitable allocation basis for manufacturing processes characterized by considerable variation in work-element processing times.

This study was limited to the existing production conditions, observed processing times, precedence relationships, and two heuristic line-balancing methods. The analysis did not consider dynamic demand variation, machine downtime, operator skill differences, batch-processing characteristics, facility-layout changes, or implementation costs. In addition, the proposed workstation configuration was evaluated analytically and has not yet been validated through long-term implementation under actual production conditions. Future studies should integrate line balancing with discrete-event simulation, capacity analysis, facility-layout evaluation, and production-cost assessment. Further comparisons with optimization-based or metaheuristic methods are also recommended to determine whether additional improvements in workload distribution, idle-time reduction, and production-flow stability can be achieved.

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