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A Comparative Evaluation of Line Balancing Methods to Enhance Sewing Line Performance

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Abstract

The textile and apparel industry of Bangladesh is the backbone of its economy, although this industry faces challenges in optimizing productivity and resource utilization due to inefficient workflows and bottlenecks. This study evaluates and compares three assembly line balancing methods, the Largest Candidate Rule (LCR), Rank Positional Weighted (RPW) Method, and Moodie Young Method with the Existing Method in a sewing line in an apparel industry. The analysis focuses on key performance metrics, including balance accuracy, resource utilization, bottleneck reduction, and material flow index (MFI). Results indicate that the Moodie Young Method demonstrates the highest resource efficiency, requiring only 39 machines and minimizing double machine workstations while achieving a moderate balance accuracy of 83%. In comparison, LCR and RPW achieve the highest balance accuracy of 90% but each requires a high number of 52 machines. The Existing Method exhibits significant inefficiencies, with the lowest balance accuracy (78%) and the highest number of bottlenecks (9). This nobility of the research is that it introduces MFI as a critical metric to evaluate material flow efficiency to ensure workflow continuity. Additionally, this approach highlights the effectiveness of heuristic techniques in balancing operational efficiency and cost-effectiveness. The study's outcomes provide a comparative analysis of 3 assembly line balancing methods in apparel industries, with potential applications in other manufacturing sectors. Future research could incorporate external variables and real-time data for further optimization.

Keywords
Assembly line balancing, Sewing line efficiency, Productivity, Bottleneck

1. Introduction
The demand for optimized workflows and minimized production delays has become essential for apparel and garment manufacturing industries that are facing competitiveness and resource constraints. The garment industry in Bangladesh is the biggest contributor to the national economy, contributing over 80% of the country's export revenue and employing a large number of workers, primarily women (Chowdhury et al. 2014). However, this sector faces significant productivity challenges due to inefficiencies and bottlenecks in production lines. Previous studies highlighted that these issues cause avoidable inefficiencies in the production line, which collectively lead to reduced lead times and production costs (Tareque et al. 2020). Furthermore, occupational health and safety concerns, particularly following the Rana Plaza tragedy (Bossavie et al. 2023), have further worsened the productivity situations

that contribute to high turnover rates and worker absenteeism (Akhter et al. 2019; Yuan et al. 2022). Studies have emphasized that line balancing can streamline production by reducing idle times and redistributing tasks (Islam & Halim 2022), positioning line balancing as an effective strategy to mitigate productivity losses (Julie et al. 2024). Therefore, addressing the productivity pitfalls and eliminating them through a balanced assembly line would benefit any sewing or other apparel production processes.

Often production demands are not fulfilled because of inefficient assembly lines, even though the resources are abundant for high productivity. This problem of low productivity arises when the resources are not utilized properly. Therefore, the purpose of line balancing is to ensure that all production tasks are accomplished at the same rate minimize idle time, and ensure efficient resource utilization (Jaggi et al. 2015), operator movement (Mazharul Islam, 2015), and operational costs (Hazir et al. 2014). Line balancing is a method used to allocate tasks evenly among workstations in an assembly line, ensuring that no single station becomes a bottleneck that slows down the production process (Battaïa & Dolgui 2013; Dolgui & Proth 2013). For example, Rahman et al. (2015) applied the Largest Candidate Rule and Rank Positional Weight methods for line balancing in apparel manufacturing, aiming to reduce idle time and improve productivity. Moreover, Bottlenecks in garment manufacturing lines often result in inefficiencies that affect production rates and labor productivity. Bappy et al. (2019) highlighted the importance of identifying and eliminating bottlenecks through work-sharing methods and task redistribution. By redistributing tasks and balancing the line, production efficiency can be significantly improved. This study contributes to the field by comparing three line-balancing methods, Largest Candidate Rule, Rank Positional Weighted, and Moodie Young in a sewing line setup in a reputed textile industry in Bangladesh.

1.1 Objectives

The objectives of this study are to evaluate and compare the effectiveness of the existing line with the improved and balanced line by applying the Largest Candidate Rule, Rank Positional Weighted, and Moodie Young method. The purpose is to optimize sewing line layouts by minimizing bottlenecks and reducing operator movement. This study aims to identify the most resource-efficient approach for enhancing productivity and workflow in a garment manufacturing environment.

2. Literature Review

Assembly line balance is a technique used at assembly stations to complete processes necessary for product production in a way that minimizes lost time. In other words, It is defined as assigning workpieces to operate systems (Das et al., 2010; Kayar & Akyalçin 2014). Assembly line balancing is an important task for industrial sectors to increase efficiency by reducing cycle time or the number of workstations (Worley & Doolen 2006). Since 1954, numerous studies have been conducted on the assembly line balance problem, which has attracted a lot of interest in the literature (Sime et al. 2019). Line balancing has been a method for improving production line issues to boost productivity ever since Henry Ford first introduced assembly lines (Wilson 2014). Lean manufacturing contributes to improving production processes and increasing employee job satisfaction (Fozzard et al. 1996; Kibira & McLean 2002). Lean manufacturing is based on the simple concept that customers will pay for the value of the services they receive but not for errors (Cortés et al. 2010; Fozzard et al.1996).

Line balancing techniques have been extensively studied in existing research articles to enhance productivity and efficiency in various manufacturing domains. Cortés et al. (2010) applied line balancing techniques to optimize a cartoon box factory's running costs and further used lean principles to optimize transportation time as well as the requisition of floor space. Whereas, Kim & Kim (2023) applied step-by-step line balancing using modular production and mixed task assignment in apparel assembly lines and were able to reduce production time and bottlenecks by optimizing task and worker assignments. Another simulation-based model was proposed by Kitaw et al. (2010), Two major decision options, one is the implementation of work centers more effectively and another is the utilization of labor work to increase system output by reducing bottlenecked processes. They didn't focus on cost optimization, whereas the study by (Pereira 2018) proposed a cost-oriented, resource-constrained multi-model assembly line balancing model by developing a hybrid algorithm to reduce costs and improve efficiency in multiple production setups.

Apart from that, Saptari et al. (2015) focused on assembly line balancing in a switched socket outlet production line by utilizing time study methods to determine standard cycle times. By redesigning the assembly line, productivity improved by 34%, which highlights the effectiveness of assembly line balancing in enhancing efficiency. Ayat et al. (2017) applied the Largest Candidate Rule (LCR) to optimize assembly line balancing in a pix cassette panel production line and improved line efficiency from 48.96% to 97.3% and reduced cycle time. It signifies LCR's potential to improve operations in manufacturing setups. Collectively, these studies highlight the critical role of line balancing in optimizing production efficiency, reducing costs, and addressing bottlenecks in several industrial setups. The current study extends the scope of applying line balancing in a textile industry by applying three different line balancing methods

3. Methods

This study utilizes a case study-based approach to evaluate and compare three line-balancing techniques, Largest Candidate Rule (LCR), Rank Positional Weighted (RPW) Method, and Moodie Young Method—in optimizing a sewing line layout in the garment manufacturing industry. The goal is to address productivity challenges by minimizing operator movement, reducing bottlenecks, and improving workstation efficiency.

3.1 Data Collection

This research was conducted in a jacket production facility, where skilled operators and workers performed cutting, sewing, and finishing operations under factory-assigned supervisors. Building on the current workflow approach, this study introduced three enhanced line-balancing techniques aimed at achieving a smoother product flow. Observational methods were used to obtain accurate task timing for each workstation and to capture idle times and task-specific bottlenecks.

The jacket sewing process in the selected industry follows a detailed workflow that begins with preparing and assembling hand pockets, which includes tasks such as zipper tacking, inserting pocket pieces, and securing seams. This is followed by preparing the inner pocket, which involves the preparation of the slider, precise positioning, and securing the edges for stability. The front and back parts are then joined through processes like attaching yokes, affixing labels, and aligning stitched sections for structural accuracy. Sleeve preparation involves joining seams, binding, and finishing cuffs to ensure a comfortable fit. The collar is then added while marking, stitching, and securing its edges to achieve a structured neckline. The assembly of the center front includes attaching edges, preparing inner front panels, and securing the zipper for functional alignment. The process concludes with final assembly, where all components of the jacket are combined, seams are secured, and the garment undergoes hemming and final adjustments. The layout of the sewing line is shown in Figure 1.

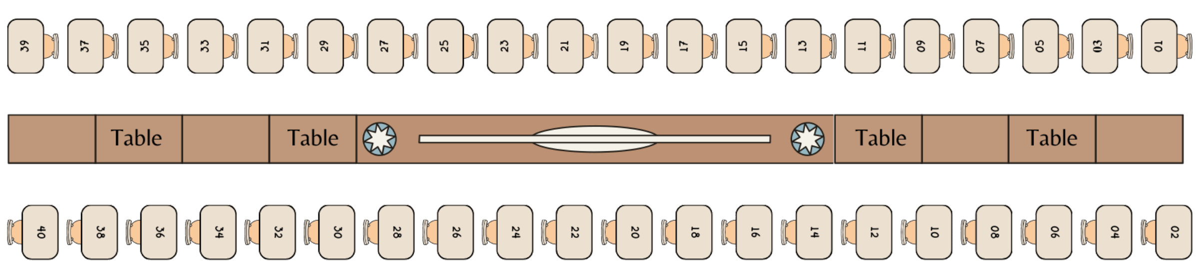


Figure 1. The current layout of the sewing line

3.2 Line Balancing Procedures

The comparative analysis applied the following line-balancing methods:

Existing Method: This current configuration maintains the initial task distribution across workstations. Observed task times were used to calculate cycle times and identify any inefficiencies within this setup.

Largest Candidate Rule (LCR): This method prioritizes tasks by descending order of task time to reduce idle time at each workstation. Tasks were assigned based on size to balance load distribution and minimize cycle time within the given layout.

Rank Positional Weighted (RPW) Method: In the RPW method, tasks are ordered by their positional weight and calculated by the sum of the task time and the times of subsequent dependent tasks. This method helps in optimizing the task sequence to balance workstation loads, considering task dependencies to achieve smoother workflow.

Moodie Young Method: This method focuses on achieving a uniform load distribution across all workstations. By minimizing idle time and adjusting task assignments, it ensures that no single workstation becomes a bottleneck, thus increasing line efficiency.

3.3 Key Performance Metrices

The effectiveness of each method was measured based on the following key metrics:
Double Machine Workstations: The number of workstations where additional machines were needed, indicating a potential increase in operator movement.

High-Capacity Utilization: The count of high-capacity workstations utilized effectively across each method.

Balance Accuracy: Calculated as the ratio of total task time to available cycle time, providing an indicator of how evenly tasks are distributed.

Operator Movement and Bottlenecks: These were assessed by monitoring the flow between workstations, tracking idle times, and observing queue formation at each station.

3.4 Comparative Analysis and Recommendations

After data collection and application of each line-balancing method, a comparative analysis was performed. Each method's impact on operational efficiency, cost, and productivity was evaluated based on the metrics outlined. The Moodie Young Method emerged as the most efficient option, providing a balanced approach with minimal operator movement and high resource utilization. Based on these results, recommendations for optimizing the sewing line layout in similar garment manufacturing settings were developed, offering insights into potential productivity gains and operational cost savings.

4. Results

The findings of this article include a comparative analysis between the existing method and the three line balancing methods.

Table 1. Comparative analysis of the three-line balancing methods with the existing methods

Method	Double Machine workstation in Layout	High Capacity	Number of machines	Bottleneck	Balance Accuracy	No of Operator	Material flow rate
Existing Method	3	14	43	9	78%	37	369%
Largest Candidate Rule	15	6	52	4	90%	36	156%
Rank Positional Weighted Method	14	8	52	4	90%	37	83%
Moodie Young Method	3	12	39	7	83%	36	237%

In order to determine the most effective strategy for sewing line layout optimization, this study assessed four different sewing line layouts, the existing method used in the industry, Largest Candidate Rule, the Rank Positional Weighted Method, and Moodie Young Method. The analysis focused on reducing the need for machines, optimizing high-capacity workstations, decreasing the need for double machine workstations (to prevent additional operator mobility), cutting expenses by using helpers where feasible and avoiding bottlenecks. Table 1 summarizes the findings of the study, boosting the use of high-capacity workstations while reducing operator movement and machine consumption. Consequently, it offers an optimized way to design a production line that is both efficient and economical.

Comparative study of the three-line balancing methods on the basis of double machine workstations, high-capacity workstations, bottleneck workstations, total machines required, and balance accuracy reveals different insights. A unique feature of the Moodie Young Method is cost effectiveness and well thought out operations to minimize total machine numbers and reduce operator movement with low double machine workstations. While its balance accuracy (83%) is less than the Largest Candidate Rule and Ranked Positional Weighted methods (both at 90%), it is a reasonably good compromise between efficiency and number of resources used. Thus, the Existing Method shows the highest bottlenecks and the lowest accuracy suggesting it is less efficient.

The comparative analysis of machine requirements and balance accuracy highlights the strengths and weaknesses of the four lines. Both LCR and RPW require the maximum number of machines with 52 each. In contrast, the Moodie Young Method demonstrates the highest efficiency, requiring only 39 machines, while the existing Method positions itself between the extremes with 43 machines. In terms of balance accuracy, the LCR method consistently achieves the highest accuracy at 90%, showcasing its superior ability to distribute workloads evenly. The Moodie Young Method strikes a balance with moderate accuracy at 83%, outperforming the Existing Method, which lags at 78%, indicating significant inefficiencies. Together, these findings emphasize the trade-offs between resource efficiency and accuracy among the evaluated methods. The bar chart to compare the machine requirements and balance accuracy of the four methods is shown in Figures 1 and 2.

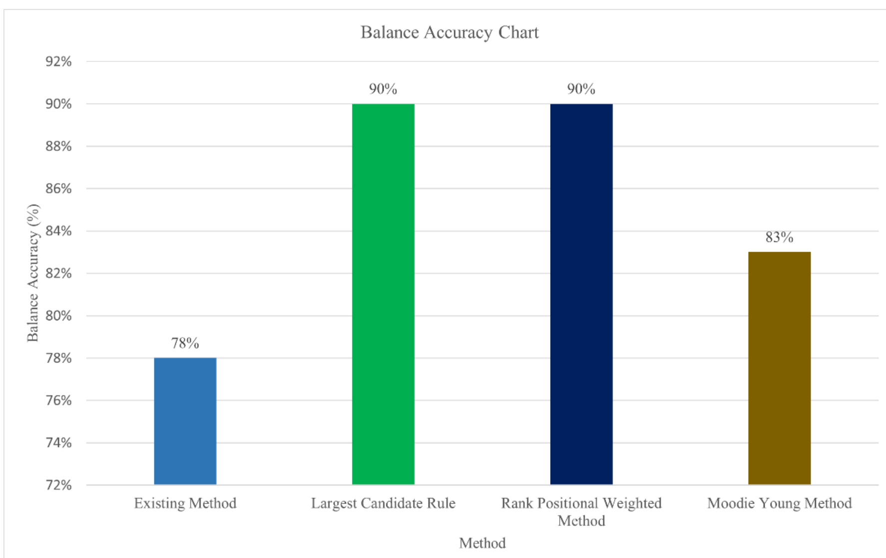


Figure 2. Comparison of balance accuracy between the methods

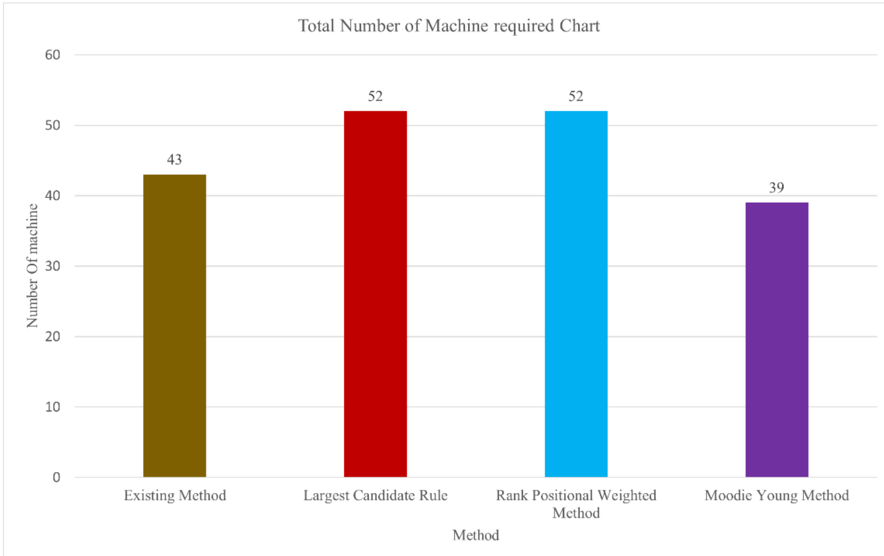


Figure 3. Comparison of required machines between the methods

The bar chart illustrates a comparative analysis of the Material Flow Index (MFI) for different production line balancing methods, revealing key insights. The Existing Method shows the highest MFI at 369%, indicating substantial inefficiencies due to excessive movement and complex transitions between workstations. This high index suggests a need for significant process re-evaluation to streamline material movement and reduce redundancy. The Largest Candidate Rule has an MFI of 156%, reflecting moderate improvement over the existing method but requiring further refinement for optimal flow. The Rank Positional Weighted Method, with the lowest MFI at 83%, demonstrates the most efficient material flow, minimizing unnecessary movement and backtracking for an effective production line. The Moodie Younge Method, at 237%, shows better efficiency compared to the Existing Method but still indicates room for further optimization. These findings emphasize the importance of selecting the appropriate balancing method to enhance material flow efficiency, reduce operational costs, and improve overall productivity.

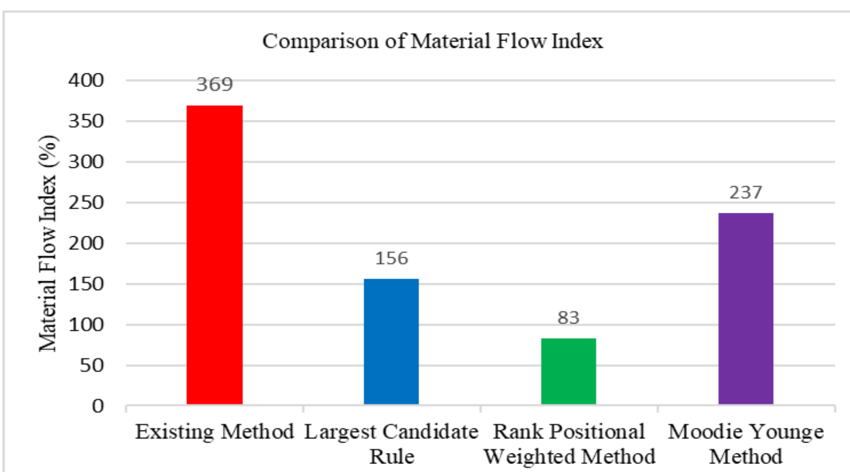
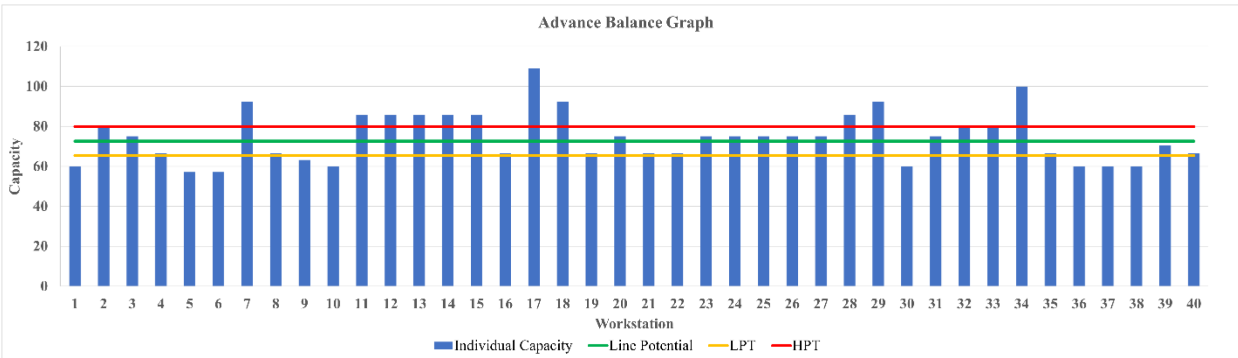
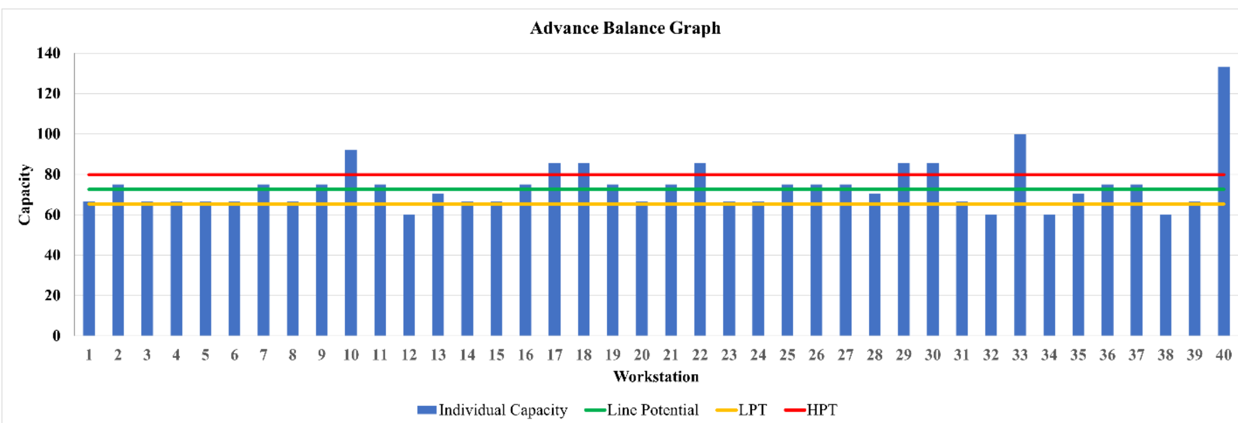


Figure 4. Comparison of required material flow index between the methods

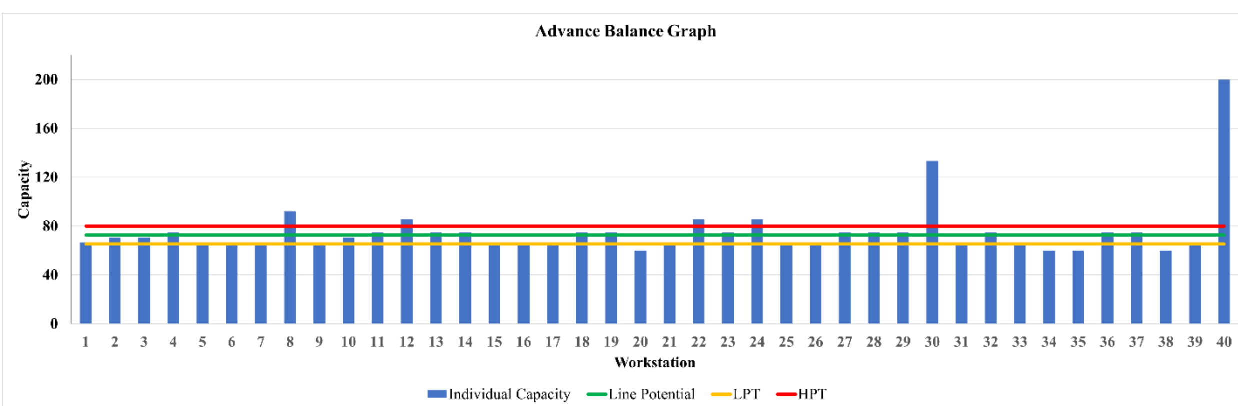
The Existing Method has the highest bottleneck workstations (9) and there are 14 high-capacity workstations. Although it demonstrated excellent load distribution through high-capacity workstation usage, the high number of bottlenecks and limited precision of balancing indicate inefficiencies and possible disruptions in productivity. On the other hand, with just 4 bottleneck workstations, this method obtained a high balancing accuracy of 90%, thus ensuring efficient workload distribution. It also featured the fewest high-capacity workstations, which limited the efficient allocation of load. There are also 6 high-capacity workstations. Whereas, with just four bottleneck workstations, the Rank Positional Weighted (RPW) Method achieved a high balance accuracy of 90%, showing performance comparable to the Largest Candidate Rule. With 8 high-capacity workstations, this method provided moderate load distribution but required a high total machine count of 52, indicating increased costs with limited additional benefits compared to other methods. The balance accuracy of 83%, though not the highest, was adequate for maintaining workflow continuity within the context of this study. Finally, the Moodie Young Method keeps double machine workstations at a minimum (3) and moderately uses high-capacity workstations (12). However, it has a higher number of bottlenecks (7) and lower balance accuracy (83%) than the RPW and Largest Candidate Rule methods. The comparison is illustrated in Figure 4.



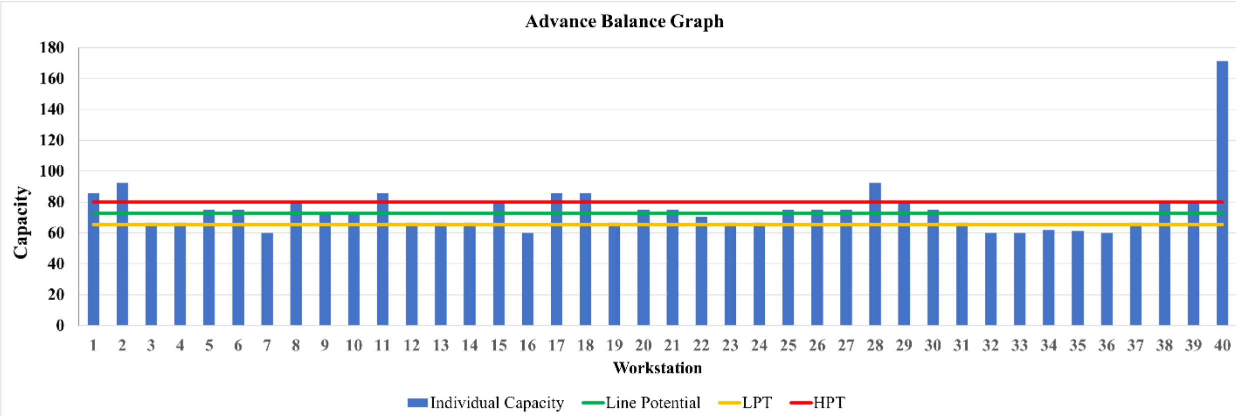
(a)



(b)



(c)



(d)

Figure 5. Comparative analysis of the advance balance graph between (a) existing method, (b) RPW method, (c) LCR method and (d) Moodie Young method. (Upper line: higher pitch time, middle line: line potential, lower line: lower pitch line)

These results compare applied line balancing methods and clarify the trade-offs between their advantages and disadvantages. For example, the Moodie Young Method stands out for its cost-effectiveness and low machine requirements (39 machines), making it suitable for cost-sensitive manufacturing environments, and also here the number of double machine workstations is low, so operator movement is comparatively lower, which increases their efficiencies and also minimizes the non-value-added cost. However, its higher number of bottlenecks (7) and moderate balance accuracy (83%), suggest it may not be ideal for operations requiring precision and consistent workflows. On the other hand, the Largest Candidate Rule (LCR) and Rank Positional Weighted (RPW) methods achieve higher balance accuracy (90%) but at the expense of requiring significantly more resources (52 machines).

These methods are better suited for scenarios prioritizing accuracy and even workload distribution despite higher operational costs, such as close-fit sewing lines. As in RPW and LCR methods, there are a higher number of double-machine workstations, so these methods require an operator who can operate multiple machines. Compared to the MYM method, the need for these types of operators is low in this case. On the other hand, in RPW and LCR, there are 4 bottleneck points, although the highest bottleneck point SMV is 1.00which is the same as the result in the MYM process. So in each method, garments will be output after 1.00 minutes, and the number of bottlenecks is not a major issue. Again, in LCR and MYM, the labor cost is lower than in the RPW method. Because, in the LCR and MYM methods there are 36 operators, and in the RPW method there are 37 operators. The wages of the operator are higher than those of a helper.

5. Discussion

The comparative analysis of line balancing methods, Largest Candidate Rule (LCR), Rank Positional Weighted (RPW), and Moodie Young Method with the existing method provides optimized sewing line layouts for optimum machine numbers, balance accuracy, and reduced bottleneck. Each method has its own benefits and does provide enough flexibility in the balanced line, but this study compares the methods to understand their differences to recommend the best method for a sewing line. Our findings align with the study by Bappy et al. (2019). who focused on improving line efficiency through dynamic work-sharing strategies but introducing a more adaptive workload distribution method. Similarly, the study by Samad et al. (2023) focused on productivity improvement through traditional methods such as Ranked Positional Weight (RPW) and Largest Candidate Rule (LCR). Our study further advanced the approach by optimizing double machine workstations and introducing material flow index (MFI) as a critical metric. Our study also progresses the understanding of line balancing in garment production by addressing limitations observed in prior research. The Moodie Young Method in our study demonstrated higher efficiency by limiting machine requirement to only 39 machines, significantly fewer than the 52 machines needed for methods like LCR and RPW, and achieved a balance accuracy of 83%, outperforming traditional methods in resource utilization.

Therefore, the decrease in the required number of machines ultimately reduces the operational costs and labor costs, since there will be a smaller number of operators needed due to the lower number of machines. Along with that, the overall productivity improvement allows a significant competitive advantage for the sewing process, since the proposed changes will lower the machine requirements to produce the same amount of finished products

This study provides a strategy for sewing lines for selecting an optimal line balancing method based on several priorities. For industries that prioritize cost optimization, the Moodie Young Method offers a trade-off and balance between resource utilization and workflow efficiency. Whereas, for operations where task accuracy and even workload distribution are more essential, the LCR and RPW methods present viable options despite their higher resource demands. While our study offers vast comparative findings in line balancing optimization, it has certain limitations. The analysis focuses on predefined metrics such as machine usage, balance accuracy, and material flow index, without accounting for external factors that may influence productivity and worker performance.

6. Conclusion

This study demonstrates comparative analysis of three-line balancing strategies that work for optimizing sewing line layout with an existing method. Although the current method may seem to have high efficiency, the proposed methods highlighted that there is enough room for productivity improvement and machine utilization. The most resource-efficient approach was the Moodie Young Method, which used fewer machines and eliminated bottlenecks while keeping a reasonable level of accuracy. Our strategy involving Moodie Young Method showed reduced resource utilization and increased operating efficiency when compared to more conventional techniques like LCR and RPW. The findings also emphasize the need for mitigation to address bottlenecks and improve material flow. Future research can proceed in the direction of applying lean principles and real-time workflow monitoring to further enhance the performance of these methods. Additionally, future studies could explore combining approaches that integrate the strengths of multiple methods to achieve a more productive solution.

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Biographies

Atiqur Rahman is a Bachelor of Science graduate in Industrial and Production Engineering from the National Institute of Textile Engineering & Research (NITER), University of Dhaka, with a strong academic record. His research interests lie in process optimization and production efficiency, with a focus on assembly line balancing. His undergraduate thesis, "Applying Various Assembly Line Balancing Methods to Improve Process Flow in a Production Process by Developing a New Process Layout," utilizes heuristic methods to enhance workflow efficiency in manufacturing environments, with specific applications in the furniture industry. Beyond academia, Atiqur's practical experience as an Industrial Engineer at Snowtex Sportswear Ltd. has solidified his skills in line balancing and process innovation within high-demand production settings. He has also gained industry insights from his internship at Kazi

Food Industries, where he focused on quality control and workforce optimization strategies within the FMCG sector. Additionally, Atiqur is a co-founder of Warishaan Appeals Ltd., where he applies his engineering and strategic management skills to advance product development and operational efficacy in garment manufacturing.

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Proma Acharjee is a dedicated educator and learner. Throughout her academic journey, she has consistently sought opportunities to enhance her knowledge and share her ideas with others, fostering a collaborative environment for mutual growth and self-improvement. Currently, Proma serves as a Lecturer at the National Institute of Textile Engineering and Research (NITER), a constituent institution of the University of Dhaka. Proma completed her undergraduate studies in Industrial and Production Engineering (IPE) at NITER, where she developed a keen interest in multidisciplinary research. Her professional career began at Soorty Textiles (BD) Limited, where she gained practical experience in the textile industry. During her studies, she undertook internships at several renowned organizations, including HATIL Furniture, Khan Brothers Group, and Ragadi Textile Ltd. These internships allowed her to explore various departments such as planning, production, quality control, and finishing, providing valuable insights into industrial operations. One of Proma's primary research interests is Assembly Line Balancing (ABL), which she developed during her undergraduate thesis titled "Applying Various Assembly Line Balancing Methods to Improve Process Flow in a Production Process by Developing a New Process Layout". Her fascination with ABL grew further through her early career experiences in the ready-made garment (RMG) sector, where optimizing workflow balance is critical for efficient production. In addition to her research in ABL, Proma has pursued various academic and professional interests.

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