Enhancing Production Performance Through Assembly Line Balancing: A Case Study Of A Motorcycle Final Assembly Line At Pt Rivercape Indonesia

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Abstrak: PT Rivercape Indonesia menghadapi kegagalan dalam mencapai target produksi tahunan sebesar 23.000 unit pada lini perakitan akhir F1, dengan realisasi produksi hanya sebesar 20.667 unit dan estimasi kesenjangan pendapatan sebesar USD 7.821.288,71. Penelitian ini bertujuan mengidentifikasi akar penyebab kegagalan tersebut, merumuskan alternatif perbaikan, dan memilih alternatif terbaik menggunakan pendekatan Assembly Line Balancing (ALB) yang didukung Current Reality Tree (CRT) dan Analytic Hierarchy Process (AHP). Metode penelitian menggabungkan observasi langsung, diskusi kelompok terarah (FGD), dan data historis perusahaan periode Januari-Februari 2026. Hasil analisis kondisi eksisting menunjukkan lini beroperasi dengan 26 workstation dan cycle time 335 detik, menghasilkan Line Efficiency 74,39% dan Balance Delay 25,61% (kategori buruk menurut Yin, 2016). Analisis CRT mengonfirmasi akar penyebab berupa ketiadaan mekanisme optimasi utilisasi workstation. Tiga alternatif perbaikan dievaluasi terhadap target cycle time 301 detik: Alternatif 1 (TSALBP Tipe 2) menghasilkan Line Efficiency 82,79%; Alternatif 2 (TSALBP Tipe 1) menghasilkan perbaikan paling signifikan dengan Line Efficiency 93,90% pada 23 workstation; dan Alternatif 3 (UALBP) menghasilkan Line Efficiency 93,59% dengan tata letak U-shape. Melalui AHP dengan Consistency Ratio 0,011, Alternatif 2 terpilih sebagai strategi terbaik dengan skor komposit 0,500. Implementasi alternatif terpilih diproyeksikan memulihkan sekitar USD 6,42 juta dari kesenjangan pendapatan yang ada melalui rencana implementasi empat fase selama sembilan bulan.

Kata kunci: lini perakitan akhir, waktu siklus, efisiensi lini, current reality tree, assembly line balancing, analytic hierarchy process.

Abstract: *PT Rivercape Indonesia has been failing to meet its annual production target of 23,000 units on Final Assembly Line F1, with actual output reaching only 20,667 units and an estimated revenue gap of USD 7,821,288.71. This study aims to identify the root cause of this shortfall, formulate improvement alternatives, and select the most appropriate alternative using an Assembly Line Balancing (ALB) approach supported by a Current Reality Tree (CRT) and the Analytic Hierarchy Process (AHP). The research method combined direct observation, focus group discussions, and internal company data collected from January to February 2026. The existing-condition analysis shows that the line operates with 26 workstations and a cycle time of 335 seconds, resulting in a Line Efficiency of only 74.39% and a Balance Delay of 25.61% (categorized as bad according to Yin, 2016). CRT analysis confirmed the root cause as the absence of a mechanism to optimize workstation utilization. Three improvement alternatives were evaluated against a target cycle time of 301 seconds: Alternative 1 (TSALBP Type 2) achieved a Line Efficiency of 82.79%; Alternative 2 (TSALBP Type 1) achieved the most substantial improvement, with a Line Efficiency of 93.90% across 23 workstations; and Alternative 3 (UALBP) achieved a Line Efficiency of 93.59% with a U-shaped layout. Using AHP with a Consistency Ratio of 0.011, Alternative 2 was selected as the most preferred strategy with the highest composite score of 0.500. Implementation of the selected alternative is projected to recover approximately USD 6.42 million of the existing revenue gap through a four-phase, nine-month implementation plan.*

Keywords: *final assembly line, cycle time, line efficiency, current reality tree, assembly line balancing, analytic hierarchy process.*

Introduction

Manufacturing is one of the key sectors of the Indonesian economy, contributing an estimated USD 265.1 billion, or 18.98% of Gross Domestic Product (GDP), in 2024 (World Bank, 2025). Within this sector, the automotive industry occupies a strategic position, contributing around USD 4.6-4.7 billion, or 1.28% of Indonesia's total GDP (Ministry of Industry of the Republic of Indonesia, 2025). Motorcycle sales in Indonesia grew from 3,660,616 units in 2020 to 6,412,769 units in 2025, although the growth rate slowed to 1.25% in 2025 (Indonesian Motorcycle Industry Association, 2026).

As one of Indonesia's motorcycle manufacturers, PT Rivercape Indonesia continuously seeks to improve productivity across its manufacturing operations. Productivity reflects the relationship between output produced and the resources required during the manufacturing process, making it a primary indicator for evaluating manufacturing system performance (Tangen, 2005). Among the five major production processes of motorcycle manufacturing (machining, welding, painting, sub-assembly, and final assembly), Final Assembly recorded the highest average cycle time at 335 seconds, since it is the last stage before inspection and shipment, meaning every unit must complete all assembly operations before proceeding further.

Workload imbalance among workstations is one of the most important factors affecting efficiency in assembly-based manufacturing systems. Internal company data from 2025 shows that Final Assembly Line F1 has the highest balance delay ratio among the company's four final assembly lines, at 25.61%, compared with Line F2 (17%), Line F3 (16%), and Line F4 (18%). According to the classification of Yin (2016), a balance delay ratio above 20% is categorized as bad, which is why Line F1 was selected as the focus of this study.

In 2025 the company made several improvement efforts by changing the workstation configuration, from 22 to 24, and finally to 26 workstations. However, cumulative production still reached only 20,667 units per year, below the company's target of 23,000 units, resulting in an estimated revenue gap of USD 7,821,288.71. This indicates that the improvement efforts undertaken so far have not been able to significantly reduce the balance delay or optimize workstation utilization.

Previous studies have extensively discussed Assembly Line Balancing (ALB) as a method for optimally distributing work elements among workstations to minimize idle time and improve line efficiency (Boysen, Fliedner, & Scholl, 2008; Battaïa & Dolgui, 2013). The Two-Sided Assembly Line Balancing Problem (TSALBP) approach was developed to accommodate two-sided line configurations (Kim, Kim, & Kim, 2000; Özcan & Toklu, 2009), while the U-shaped Assembly Line Balancing Problem (UALBP) approach offers an alternative layout that can increase operator allocation flexibility (Miltenburg & Wijngaard, 1994; Oksuz, Buyukozkan, & Satoglu, 2017). To select the best improvement alternative from several conflicting criteria, the Analytic Hierarchy Process (AHP) is widely used because of its ability to handle multi-criteria decision making systematically (Saaty, 1980; Vaidya & Kumar, 2006).

Based on the above, this study aims to (1) analyze the root cause of the failure to achieve the production target on Final Assembly Line F1, (2) formulate improvement alternatives using an assembly line balancing approach, and (3) select the best improvement alternative using AHP to increase production output and minimize the resulting revenue gap.

Methods

This study uses a quantitative approach with a case study design on Final Assembly Line F1 of PT Rivercape Indonesia. The research subjects covered all workstations on the line, with supporting informants consisting of the Production Manager, Section Head, Line Head, Subline Head, Leaders, and operators, selected through purposive sampling based on their direct involvement in the production process. Data were collected through three main techniques: direct observation of the work sequence, cycle time, and operator workload; focus group discussions (FGD) with relevant stakeholders to validate the problems and causes of line imbalance; and internal historical company data for the period of January-February 2026, covering production targets, actual production, work element times, and balance delay ratios. Data validity was maintained through triangulation of observation data, FGD results, and historical company data, while informant confidentiality was ensured through anonymization of the FGD results and the use of work element codes instead of detailed descriptions. Data analysis was carried out in stages, beginning with mapping the production process using a SIPOC diagram, followed by stakeholder analysis, and then root-cause identification using a Current Reality Tree (CRT). Next, an assembly line balancing analysis was performed to formulate improvement alternatives, namely TSALBP Type 2 (Alternative 1), TSALBP Type 1 (Alternative 2), and UALBP (Alternative 3), which were evaluated based on Line Efficiency, Balance Delay, and Smoothing Index against a target cycle time of 301 seconds. The best alternative was selected using the Analytic Hierarchy Process (AHP) based on five criteria (Line Efficiency, Smoothing Index, number of workstations, investment cost, and implementation feasibility) through pairwise comparisons by internal subject matter experts, with a Consistency Ratio below 0.10 as the success indicator. As additional validation, a takt time-based sensitivity analysis and an exploration of the theoretical efficiency limit using the TSALBP Type E formulation were conducted.

Results and Discussion

The existing-condition analysis shows that Final Assembly Line F1 consists of 343 work elements distributed across 26 workstations in a two-sided line configuration. Based on the calculation results, Workstation 11 has the highest total cycle time of 335 seconds with no idle time, making it the bottleneck that determines the overall cycle time of the line. Several other workstations, such as WS 4, WS 5, and WS 9, have workloads close to the cycle time limit (319-322 seconds), while WS 7, WS 13, WS 14, and WS 19 have much larger idle times, ranging from 137 to 173 seconds. This condition results in a Line Efficiency of 74.39% and a Balance Delay of 25.61%, which is categorized as bad according to Yin (2016), along with a Smoothing Index of 494.49, indicating high workload variation among workstations.

The results of the focus group discussions with the Production Manager, Section Head, Line Head, Subline Head, Leaders, and operators confirmed three main problems: the failure to achieve the production target, significant workload variation among workstations, and unresolved line inefficiency despite several previous improvement efforts. The Current Reality Tree (CRT) analysis built from these findings identified that the root cause of all the problems is the absence of an effective mechanism to optimize workstation utilization, which simultaneously causes bottlenecks at several workstations and excess capacity (idle time) at others.

Based on this root cause, three improvement alternatives were formulated and evaluated against a target cycle time of 301 seconds. Alternative 1 used the TSALBP Type 2 approach, redistributing work elements within the existing 26-workstation configuration, resulting in a Line Efficiency increase to 82.79% and a Balance Delay reduction to 17.21%. Alternative 2 used the TSALBP Type 1 approach, redistributing work elements while reducing the number of workstations to 23, and achieved the most substantial improvement among the three alternatives, namely a Line Efficiency of 93.90%, a Balance Delay of 6.10%, and a Smoothing Index of 120.67. Alternative 3 used the UALBP approach, reconfiguring the line into a U-shaped layout without requiring a dedicated turnaround workstation or jig, resulting in a Line Efficiency of 93.59%, a Balance Delay of 6.41%, and a Smoothing Index of 266.94 across 23 workstations. A performance comparison of the three alternatives is presented in Table 1.

Table 1. Performance Comparison of the Improvement Alternatives

Indicator	Existing	Alternative 1 (TSALBP-2)	Alternative 2 (TSALBP-1)	Alternative 3 (UALBP)
Number of workstations	26	26	23	23
Cycle time (s)	335	301	300	301
Line Efficiency	74.39%	82.79%	93.90%	93.59%
Balance Delay	25.61%	17.21%	6.10%	6.41%
Smoothing Index	494.49	-	120.67	266.94

All three alternatives were technically feasible and able to meet the target cycle time, confirming that assembly line balancing is an effective approach for addressing the workload imbalance identified as the root cause of the production shortfall. The best alternative was selected using the Analytic Hierarchy Process (AHP) with five evaluation criteria, namely Line Efficiency, Smoothing Index, number of workstations, investment cost, and implementation feasibility, weighted at 0.439, 0.255, 0.156, 0.092, and 0.058 respectively, with a Consistency Ratio of 0.011 indicating the reliability of the expert judgments. Based on the resulting composite scores, Alternative 2 (TSALBP Type 1) was selected as the best improvement strategy with a score of 0.500, compared with 0.252 for Alternative 1 and 0.247 for Alternative 3.

Implementation of Alternative 2 is projected to reduce the cycle time from 335 to 300 seconds, increase Line Efficiency from 74.39% to 93.90%, decrease Balance Delay from 25.61% to 6.10%, reduce the Smoothing Index from 494.49 to 120.67, decrease total idle time from 2,165 to 444 seconds, and reduce the number of active workstations from 26 to 23. Considering a realistic implementation effectiveness of 82%, based on workforce readiness assessment, Line Efficiency is projected to reach approximately 90.13% and recover approximately USD 6.42 million of the existing USD 7.83 million revenue gap. A takt time-based sensitivity analysis shows that the 23-workstation configuration remains stable within a cycle time range of 297-304 seconds, while the TSALBP Type E exploration found a theoretical efficiency limit of 95.22% at 21 workstations with a cycle time of 324 seconds; however, this value exceeds the required takt time and therefore cannot meet the production demand target. These findings strengthen the validity of selecting Alternative 2 as the most suitable solution in terms of both operational efficiency and demand fulfillment.

To support successful implementation, a four-phase, nine-month implementation plan was designed, consisting of line balancing implementation, workload monitoring and stabilization, operator redeployment and cross-training, and performance review and line stabilization. This plan takes workforce aspects into account, including the redistribution of operator workload and the cross-training needs arising from changes in workstation assignments, so that the proposed technical improvements can be implemented sustainably without neglecting the readiness of human resources on the production line.

Conclusion

This study concludes that the root cause of the failure to achieve the production target on Final Assembly Line F1 of PT Rivercape Indonesia is the absence of an effective mechanism to optimize workstation utilization, which causes an imbalance in workload distribution among workstations. The existing condition, with 26 workstations and a cycle time of 335 seconds, resulted in a Line Efficiency of only 74.39% and a Balance Delay of 25.61%, leading to a production shortfall of 2,333 units and an estimated revenue gap of USD 7,821,288.71 per year. Of the three improvement alternatives formulated and evaluated using the Analytic Hierarchy Process, Alternative 2 (TSALBP Type 1) was selected as the best improvement strategy with the highest composite score of 0.500, capable of increasing Line Efficiency to 93.90% across 23 workstations and potentially recovering approximately USD 6.42 million of the existing revenue gap through a phased nine-month implementation. Additional validation through takt time sensitivity analysis and the TSALBP Type E exploration further confirms that the selected alternative is the most optimal and balanced solution between operational efficiency and production demand fulfillment. Future research is recommended to validate these findings by observing actual post-implementation performance, to extend the analysis to the company's other assembly lines, and to develop a more quantitatively data-driven AHP approach to reduce the subjectivity of expert judgments.

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