

Production Line Efficiency Improvement Using the Line Balancing Method on the 3W Frame Welding Line at PT X

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ARTICLE INFO

Article history

Received: July 2026

Revised: September 2026

Accepted: September 2026

Keywords

Balance Delay

Line Efficiency

Line Balancing

Ranked Positional Weight

Work Instruction

Yamazumi Chart

ABSTRACT

Manufacturing assembly lines frequently face operational inefficiencies due to unbalanced workloads and discrepancies between legacy Work Instructions (WI) and actual shop-floor cycle times. At PT X, the 3W Frame Welding Line exhibited a low initial Line Efficiency (LE) of 54.83% and a 3,290-second time data gap between documented procedures and actual operations, resulting in severe line imbalances and restricted output. This study aims to eliminate the time data discrepancy, redesign the workload allocation across workstations within the target takt time, and evaluate the resulting operational and financial improvements. The methodology integrates the Eight Steps problem-solving framework with the Ranked Positional Weight (RPW) heuristic method and Lean visualization tools, including Standardized Work Combination Tables (SWCT), Standardized Work Charts (SWC), and Yamazumi Charts based on stopwatch time studies. The results show that standardization successfully eliminated the 3,290-second data gap with 100% document accuracy. Following line balancing across three workstations, LE increased significantly from 54.83% to 94.67%, Balance Delay (BD) dropped from 45.17% to 5.33%, and daily production capacity doubled from 10 to 20 units without overtime. This study concludes that combining the RPW method with visual standardized work effectively resolves shop-floor bottlenecks and data asynchrony, delivering a projected Net Quality Income (NQI) of IDR 4,596,249,600 per year.

1. Introduction

In today's highly competitive manufacturing landscape, operational efficiency serves as a critical determinant in maintaining global market competitiveness. The throughput stability of assembly lines is frequently disrupted by unequal workload distribution among consecutive stations, inevitably creating bottleneck constraints [1]. This imbalance disrupts production flow due to significant deviations between actual cycle times and the target takt time that governs the production rhythm [2][3]. To establish a balanced workflow, standard Work Instructions (WI) must be drafted accurately as an objective benchmark for efficiency enhancements [4]. Deploying line balancing techniques is vital to allocate work elements proportionally and minimize idle time [5]. In lean manufacturing, this standardization is operationalized through Standardized Work Combination Tables (SWCT) to chronologically map manual and machine process times, supported by Yamazumi Charts as visual instruments to transparently track workstation loads [6], [7].

PT X is a premier automotive component manufacturer operating as a Tier-1 supplier for major Original Equipment Manufacturers (OEMs) in Indonesia. To expand its commercial vehicle operations, the company

manages an independent 3-Wheel (3W) Division to design and produce three-wheeled vehicles. This study specifically focuses on the 3W Frame Welding Line, as the final assembly throughput heavily relies on the stable supply of main structural frames fabricated on this line. Initial line assessments revealed that the 3W Frame Welding Line achieved an initial Line Efficiency (LE) of only 54.83%, falling well below the company's internal minimum baseline of 85.00%. This poor efficiency directly corresponds to a high Balance Delay (BD) of 45.62%, indicating that nearly half of the available production time was lost to balance loss and operator idle time. Operationally, this imbalance caused severe line bottlenecks, elevated work-in-process inventory, and restricted daily production output to only 10 units per day.

A thorough time study audit revealed that this line imbalance was fundamentally driven by a 3,290-second discrepancy between the cycle times documented in legacy work instructions and actual shop-floor operations. This 3,290-second gap represented an accumulation of unrecorded process expansions, where work elements expanded from 54 to 60 without systematic document updates. Consequently, using outdated WI data as a baseline for line balancing rendered traditional task allocations ineffective and inaccurate [8].

Previous studies applying the Ranked Positional Weight (RPW) method successfully optimized line efficiency—for instance, reducing balance delay and increasing line efficiency [9], [10]. Furthermore, integrating standardized work tools and visual management layouts has been shown to lower idle times significantly [11]. Modern heuristic approaches continuously demonstrate that structured line reorganization minimizes operator fatigue and balances cycle times [12]. However, existing studies predominantly assume that the baseline time data used for RPW calculations are accurate, overlooking the widespread industrial challenge of time data asynchrony between documented WIs and actual field execution [13], [14]. Balancing a line using unvalidated WI data risks generating unrealistic task re-allocations.

To address this research gap, the urgency of this study lies in establishing data integrity prior to line reorganization. The primary methodological contribution and novelty of this paper rests on a multi-stage integrative framework combining the Eight Steps problem-solving framework, Lean Standardized Work instruments (SWCT and Yamazumi Charts), and the RPW heuristic algorithm. This integrated approach ensures that shop-floor process times are fully synchronized and validated before executing mathematical line balancing.

The direct objective of this study is threefold: first, to identify and eliminate the 3,290-second time data discrepancy between legacy work instructions and actual shop-floor operations; second, to redesign workload distribution across workstations using the RPW algorithm integrated with visual Lean standardized work tools; and third, to evaluate the quantitative operational improvements—specifically targeting a Line Efficiency above 85.00%, a minimized Balance Delay, and an increase in daily output capacity—while projecting the financial impact in terms of Net Quality Income (NQI). The research contributes a practical improvement proposal in the form of synchronized Work Instructions, standardized work documents, and a more balanced distribution of workload among workstations. The success of the research is determined using measurable indicators, including an increase in Line Efficiency, a reduction in Balance Delay, synchronization of work-element data between the Work Instruction and actual conditions, and an increase in production output without additional overtime.

2. Method

2.1 Type and Approach of Research

This study implements an applied descriptive-analytical case study design supported by a quantitative industrial engineering approach. Operational line balancing performance is evaluated numerically to compare key performance indicators before and after the system restructuring.

2.2 Object and Scope of Research

The object of this research is strictly confined to the 3W Frame Welding Line fabricating the Assy Main Frame at the 3-Wheel Division of PT X. The population consists of all operational cycle times across all manufacturing processes on the line, covering both upstream preparation (cutting, bending, notching, drilling, and fine boring) and downstream welding operations.

The research sample comprises 60 defined work elements across the line. A purposive sampling technique was employed, combined with a continuous stopwatch time study method. To ensure statistical reliability and accuracy, observations were conducted over three consecutive production cycles for each work element under standard operator working conditions and normal working speed.

2.3 Data Collection Techniques

Primary data were gathered directly on the shop floor (*Genba*) using stopwatch time study measurement techniques. The research instruments used for data collection and analysis include:

- **Measurement Instruments:** Digital stopwatches (for precise cycle time recording) and video cameras (for micromotion movement waste analysis).
- **Analytical & Visualization Instruments:** Physical and digital data logs formatted as Standardized Work Combination Tables (SWCT), Standardized Work Charts (SWC), Yamazumi Charts, and Cause-and-Effect (Fishbone) Diagrams.
- **Computational Tools:** Spreadsheet software (Microsoft Excel) to execute arithmetic line balancing algorithms and matrix calculations.

Secondary data were extracted from internal corporate archives, including legacy Work Instruction (WI) sheets, historical customer demand logs, Net Quality Income (NQI) reports, and relevant manufacturing journals..

2.4 Tools and Materials Used

The research tools consisted of digital stopwatches, video cameras for micromotion movement waste analysis [15], Microsoft Excel for arithmetic line balancing calculations, and physical data logs formatted as Standardized Work Combination Tables (SWCT) and Yamazumi baseline borders [16].

2.5 Research Procedures or Stages

The operational problem-solving sequence was carried out step by step according to the structured Eight Steps Framework [17], [18]:

1. **Step 1 (Theme Selection):** Analyzing the division's highest idle time via a Pareto Chart.
2. **Step 2 (Target Setting):** Specifying quantitative improvement goals bound by SMART parameters.
3. **Step 3 (Current Situation Analysis):** Mapping out floor operations against QCDSMP criteria.
4. **Step 4 (Root Cause Analysis):** Deconstructing the underlying causes of the line's high balance delay using a Fishbone Diagram.
5. **Step 5 (Countermeasure Planning):** Formulating systematic countermeasure paths mapped in a 5W+1H matrix layout.
6. **Step 6 (Countermeasure Implementation):** Restructuring the work element distribution for three operator positions via the RPW method, installing a stable daily batch production flow in the preparation line, and drafting revised SWCT layouts and Yamazumi Charts.
7. **Step 7 (Result Evaluation):** Verifying the line efficiency changes via a systematic Before vs. After data check.
8. **Step 8 (Standardization & Follow-up):** Formally authorizing the new standard work documentation to prevent process regression.

2.6 Data Analysis Techniques

Quantitative line balancing metrics were calculated using the standard Industrial Engineering formulas below [16], [19]:

- Takt Time (TT) :

$$TT = \frac{\text{Available Effective Working Time}}{\text{Customer Demand Volume}} \quad (1)$$

- Line Efficiency (LE) :

$$LE = \frac{\sum_{i=1}^n t_i}{K \times CT_{max}} \times 100\% \quad (2)$$

- Balance Delay (BD) :

$$BD = 100\% - LE \quad (3)$$

3. Results and Discussion

3.1 Step 1: Theme Selection and Problem Identification

The project was initiated with a data-driven evaluation of idle time accumulations across the 3-Wheel Division's main assembly layouts. Historical data analyzed using Pareto analysis indicated that the 3W Frame Welding Line contributed the most critical bottleneck waste, exhibiting an initial Balance Delay (BD) of

45.17% and an average of 148 seconds of unproductive idle time per unit. This operational disruption was driven by severe time data asynchrony. A physical stopwatch time study audit revealed a massive data gap of 3,290 seconds; the actual shop floor required 5,143 seconds across 61 active processes, whereas the legacy standard work instructions only accounted for 8,434 seconds across 54 elements. This statistical mismatch prevented objective task allocation and caused severe material flow stagnation.

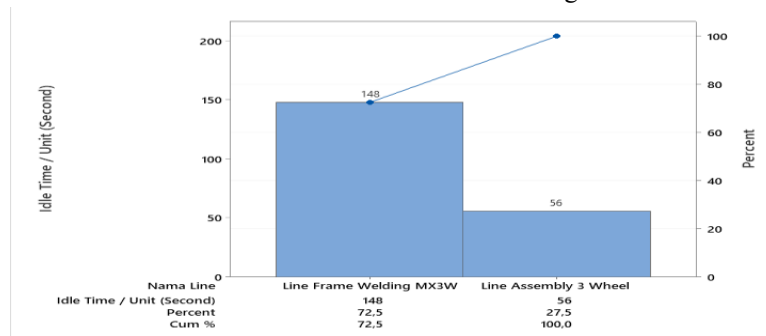


Fig. 1 Pareto Chart of Idle Time Production Line 3 Wheel

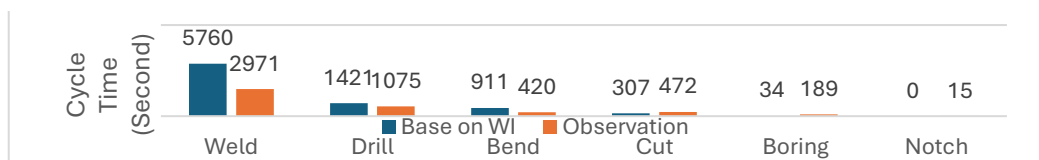


Fig. 2 Cycle Time Base on WI Line Frame Welding MX3W

3.2 Step 2: Target Setting

Bound by the SMART engineering framework, definitive performance boundaries were approved by the plant management to drive the continuous improvement cycle. The primary objective was established to systematically elevate the production line's Line Efficiency (LE) from an inefficient 54.83% baseline up to a minimum target of 90.00%, successfully surpassing the company's internal manufacturing threshold of 85.00%. A secondary target was established to achieve a 100% data accuracy matching rate for the newly engineered Work Instructions (WI) without expanding standard operating hours or requiring overtime expenses. The improvement targets are shown in Table 1.

Table 1. SMART Analysis

No	SMART Criteria	Improvement Target Description
1	Specific	Improving the line balancing of the 3-Wheel frame through workload redistribution to minimize balance delay, along with synchronizing the cycle times in the Work Instructions (WI) with the actual shop-floor cycle times.
2	Measurable	Increasing Line Efficiency from the baseline of 54.83% to a minimum of 90.00% (+35.62%) as mandated by plant management, while ensuring a 100% data accuracy matching rate for the Work Instruction (WI) documentation based on actual field operations.
3	Achievable	This target was achieved through the line balancing method for element redistribution without expanding current resources or adding headcount, supported by anchoring actual time study data into the Work Instructions (WI) to deliver an applicable and valid working standard for team members.
4	Relevant	Supporting the throughput productivity and output stability of the 3-Wheel Division at PT X by stabilizing workload tracking within the Work Instructions (WI). This ensures a valid standard reference to sustain quality consistency and manufacturing pace on the 3W Frame Welding Line.
5	Time - Bound	The continuous improvement targets are were established for completion by June 2026.

3.3 Step 3: Current Situation Analysis

A direct shop-floor evaluation (*Genba*) was carried out to assess operational conditions against the standardized QCDSMP indicators. While quality and safety parameters remained within stable operating conditions, critical "Not OK" (NOK) conditions were identified across the Delivery, Morale, and Productivity indexes. The line suffered from highly erratic cycle distributions relative to the target takt time, which caused

extreme physiological fatigue and workload variance among the operator crew due to unstandardized station tasks. Table 2 presents the current situation analysis based on QCDSMP parameters.

Table 2. Current Situation Analysis Based on QCDSMP Parameters

No	Indicator	Parameter	Target	Actual	Status
1	Cost	Material Handling Waste	Efficient & Standardized	No Standardized Method	NOK
2	Delivery	Line Efficiency	90%	54.87%	NOK
3	Safety	Unsafe Condition & Action	0 Incidents	0 Incidents	OK
4	Morale	Workload	Balanced	Unbalanced / Unequal	NOK
5	Productivity	Cycle Time vs. Takt Time	Cycle Time $\leq$ Takt Time	Absence of Station Task Allocation	NOK

3.4 Step 4: Root Cause Analysis

To systematically deconstruct the high balance delay, a Fishbone Diagram was deployed to isolate the core operational constraints across environmental, machine, material, and human factors. Machine and material elements were verified as stable, meaning the true root causes stemmed directly from three variables: (1) *Method*: the complete lack of a standardized process sequence blueprint, (2) *Man*: the absence of accurate workload mapping to anchor task assignments, and (3) *Measurement*: a deficiency in visual tracking controls to flag line imbalances immediately.

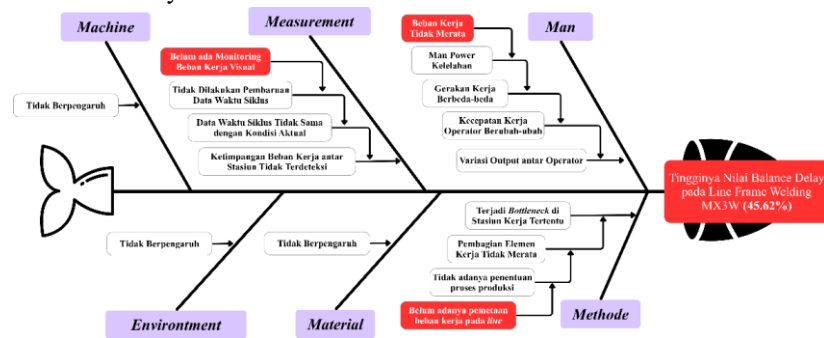


Fig. 3. Fishbone Diagram

3.5 Step 5: Countermeasure Planning

A structured 5W+1H management matrix was developed to establish targeted engineering remedies for the isolated root causes. The engineering action plan specified: (1) conducting a micro-element cycle audit to revise the outdated work instructions, (2) applying the heuristic Ranked Positional Weight (RPW) algorithm to balance the main welding area, and (3) drafting high-visibility Yamazumi stacked bar charts and Standardized Work Combination Tables (SWCT) to anchor daily line tracking. The resulting countermeasures are presented in Table 3.

Table 3. 5W + 1H Analysis

No	Factor	What	Why	Who	Where	When	How
1	Man	Workload imbalance and operator fatigue.	Absence of an accurate workload mapping to define standard task assignments.	Zulfahmi and the Manufacturing Team	MX3W Frame Welding Line Area	Dec-25	Applying Line Balancing to redistribute work elements, developing Standardized Work Combination Tables (SWCT), and creating Standardized Work Charts (SWC) to standardize the

No	Factor	What	Why	Who	Where	When	How
							operational sequence.
2	Method	Work Instruction (WI) documentation is out of sync with actual shop-floor activities.	Absence of a line workload mapping to serve as a baseline for process planning.	Zulfahmi and the Manufacturing Team	MX3W Frame Welding Line Area	Nov-25	Re-mapping the production process sequence and revising the Work Instructions (WI) to align with the optimized, actual working sequence.
3	Measurement	Severe cycle time disparities between workstations remain undetected.	Absence of a visual workload monitoring system along the production line.			Dec-25	Constructing a Yamazumi Chart for workstation workload visualization to streamline bottleneck identification and line efficiency tracking.

3.6 Step 6: Countermeasure Implementation

The implementation phase was carried out incrementally in collaboration with the internal manufacturing team through the following structured initiatives:

1. Standardization and Revision of Work Instruction (WI) Documents

The initial phase focused on conducting a micro-element work cycle audit and updating the operational guidance documentation for line operators. The newly revised WI format was enhanced with visual representations of correct standardized movements alongside defined boundary criteria for process quality checks.

Fig. 4. New Work Instruction

2. Implementation of a Batch Production System in the Upstream Area (Preparation Area)

Within the component preparation station, a calculated Batch Production sequence was instituted across a 5-day operational cycle. This tactical allocation was closely aligned with the actual capacity of the 2 actual manual operators. Task assignments for cutting, bending, drilling, and notching elements were systematically structured to ensure a rhythmic and continuous material supply to the subsequent welding area, successfully eliminating mid-line Work in Process (WIP) inventory bottlenecks and while avoiding overtime labor requirements. The resulting production plan is shown in Table 4.

MP	Day 1					Day 2					Day 3				
	Process	Part	Cycle time	Idle time	Description	Process	Part	Cycle time	Idle time	Description	Process	Part	Cycle time	Idle time	Description
MP 1	Bend	Bottom Frame L 1	9217	17783	-	Bend	Bottom Frame R 2	6242	20758	-	Cut	Top Frame	784	26216	-
	Bend	Bottom Frame R 1	9217	8566	-	Cut	Bottom Frame R	5504	15254	-	Bend	Front Guard L	11438	14778	-
	Bend	Bottom Frame L 2	7404	1162	-	Cut	Bottom Frame L	5504	9750	-	Bend	Brake System Cross Pipe	6021	8757	-
	Bend	Bottom Frame R 2	7404	-6242	WIP	Cut	Top Frame 1	5207	4543	-	Cut	Brake System Cross Pipe	3622	5135	-
						Cut	Top Frame 2	5327	-784	WIP	Cut	Front Guard L	5800	-665	-
MP 2	Bend	Steering Handle	8119	18881	-	Drill	Bottom Frame R 2	6242	20758	Ikut Bend	Drill	Bracket Stabilizer R 1	2218	24782	-
	Fine Boring	Head Pipe 185	10200	8681	-	Bend	Top Frame	6912	13846	-	Drill	Bracket Stabilizer R 2	18129	6653	-
	Drill	Steering Handle	2724	5957	-	Notch	Top Frame	1500	12346	-	Drill	Bracket Brake System	2008	4645	-
	Drill	Bottom Frame L	4604	1353	-	Drill	Top Frame	2514	9832	-	Drill	Middle Cross Frame	3201	1444	-
	Drill	Bottom Frame R	5204	-3851	WIP	Drill	Bracket Stabilizer 1	6025	3807	-	Drill	Front Cross Member	4800	-3356	WIP
Day 4						Day 5									
MP 1	Process	Part	Cycle time	Idle time	Description	Process	Part	Cycle time	Idle time	Description					
	Cut	Front Guard L	665	26335	-	Cut	Rear Support Bottom Frame L	5674	21326	-					
	Cut	Extension Pipe	7709	18626	-	Cut	Stopper Break System	8200	13126	-					
	Cut	Rear Bracket Leaf Spring	9400	9226	-	Drill	Support Vertical Outer R	3900	9226	-					
	Cut	Rear Support Bottom Frame L	14900	-5674	WIP	Drill	Extension 1	3201	6025	-					
MP 2	Drill	Front Cross Member	3356	23644	-	Drill	Long Member R 2	5163	21837	-					
	Drill	Long Member L 1	6924	16720	-	Drill	Long Member R 3	1111	20726	-					
	Drill	Long Member L 2	6924	9796	-	Drill	Main Cross Member 1	5404	15322	-					
	Drill	Long Member L 3	1111	8685	-	Drill	Main Cross Member 2	3415	11907	-					
	Drill	Long Member R 1	6924	1761	-	Drill	Main Cross Member 3	3211	8696	-					
	Drill	Long Member R 2	6924	-5163	WIP	Drill	Rear Cross Member 1	3201	5495	-					
						Drill	Rear Cross Member 2	4518	977	-					

3. Implementation of the Ranked Positional Weight (RPW) Heuristic Algorithm in the Welding Area

At the core welding area, workload was re-engineered utilizing the heuristic Ranked Positional Weight (RPW) algorithm. This method was specifically deployed due to its capability to deliver a highly systematic, logical, and measurable workload distribution based on mathematical positional weight scores. The detailed calculation steps and element allocation procedures are executed as follows:

1.) Identification of Work Elements and Precedence Constraints

The initial stage begins by breaking down the Assy Main Frame welding activities into 14 primary work elements. The technical sequential dependencies (precedence) are determined based on the actual physical assembly sequence on the shop floor to prevent procedural errors. This operational sequence is visualized through a precedence diagram, as shown in Figure 5.

Table 4. Precedence Table

No	Part	Precedence	Cycle Time (Sec)
1	SUB ASSY BOTTOM FRAME L	-	307
2	SUB ASSY BOTTOM FRAME R	-	217
3	SUB ASSY MIDDLE FRAME	-	282
4	SUB ASSY TOP FRAME	-	287
5	SUB ASSY FRONT BRACKET LEAF SPRING	-	66
6	SUB ASSY MIDDLE CROSS FRAME	-	82
7	FRONT ASSY MAIN FRAME	1, 2, 3, 4	303
8	SUB ASSY REAR FRAME	5, 6	300
9	SUB ASSY BRAKE SYSTEM	-	88
10	SUB ASSY FRONT FRAME	7	174
11	SUB ASSY MAIN REAR FRAME	8, 9	150
12	ASSY MAIN FRAME	10, 11	361
13	SUB ASSY ENGINE MOUNTING	-	137
14	SUB ASSY FRONT GUARD LR	-	134

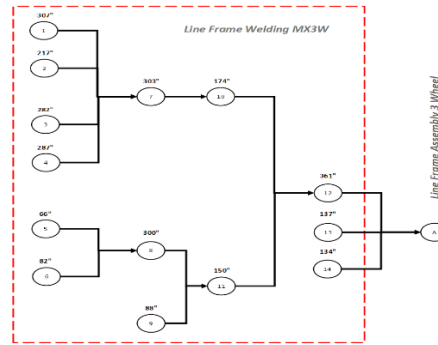


Fig. 5. Precedence Diagram

2.) Construction of the Precedence Matrix

To mathematically validate the network sequence logic, a precedence matrix was constructed utilizing binary logic. Table 6 presents the precedence matrix. A value of 1 indicates that the row element acts as an absolute and mandatory predecessor for the column element, whereas a value of 0 indicates the absence of a direct sequential dependency.

Table 5. Precedence Matrix

Predecessor Operation		Follower Operation													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	307	1	0	0	0	0	0	1	0	0	1	0	1	0	0
2	217	0	1	0	0	0	0	1	0	0	1	0	1	0	0
3	282	0	0	1	0	0	0	1	0	0	1	0	1	0	0
4	287	0	0	0	1	0	0	1	0	0	1	0	1	0	0
5	66	0	0	0	0	1	0	0	1	0	0	1	1	0	0
6	82	0	0	0	0	0	1	0	1	0	0	1	1	0	0
7	303	0	0	0	0	0	0	1	0	0	1	0	1	0	0
8	300	0	0	0	0	0	0	0	1	0	0	1	1	0	0
9	88	0	0	0	0	0	0	0	0	1	0	1	1	0	0
10	174	0	0	0	0	0	0	0	0	0	1	0	1	0	0
11	150	0	0	0	0	0	0	0	0	0	0	1	0	0	0
12	361	0	0	0	0	0	0	0	0	0	0	0	1	0	0
13	137	0	0	0	0	0	0	0	0	0	0	0	0	1	0
14	134	0	0	0	0	0	0	0	0	0	0	0	0	0	1

3.) Calculation of Ranked Positional Weight (RPW) Scores

The Ranked Positional Weight (RPW) score for each individual operation is computed by summing the cycle time duration of the element itself with the cumulative durations of all downstream follower elements located along the subsequent routing path within the precedence matrix, as presented in Table 7.

Table 6. Ranked Positional Weight Scores

Predecessor Operation		Follower Operation														Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	307	1	0	0	0	0	0	303	0	0	174	0	361	0	0	1145
2	217	0	1	0	0	0	0	303	0	0	174	0	361	0	0	1055
3	282	0	0	1	0	0	0	303	0	0	174	0	361	0	0	1120
4	287	0	0	0	1	0	0	303	0	0	174	0	361	0	0	1125
5	66	0	0	0	0	1	0	300	0	0	150	361	0	0	0	877
6	82	0	0	0	0	0	1	300	0	0	150	361	0	0	0	893
7	303	0	0	0	0	0	0	0	0	0	174	0	361	0	0	838
8	300	0	0	0	0	0	0	0	1	0	150	361	0	0	0	811
9	88	0	0	0	0	0	0	0	0	1	150	361	0	0	0	599
10	174	0	0	0	0	0	0	0	0	0	0	361	0	0	0	535
11	150	0	0	0	0	0	0	0	0	0	0	0	1	0	0	511
12	361	0	0	0	0	0	0	0	0	0	0	0	0	1	0	361
13	137	0	0	0	0	0	0	0	0	0	0	0	0	0	1	137
14	134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	134

As an illustrative example of the critical path search metric, the RPW score for Operation 1 is 1,145 seconds, derived from the cycle time of Operation 1 itself (307 seconds) combined with the cumulative

durations of all its subsequent follower elements within the precedence diagram, which consist of Element 7 (303 seconds), Element 10 (174 seconds), and Element 12 (361 seconds).

4.) Determination of Operation Priority Rankings and Minimum Workstations

Once the positional weight score for each element is obtained, all operations are sorted in descending order from the largest to the smallest RPW value to establish the priority ranking for workstation allocation. Table 8 shows that the element with the largest positional weight is prioritized to be assigned first within the workstation allocation procedure.

Table 7. Priority Table

No	Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Operation	1	4	3	2	6	5	7	8	9	10	11	12	13	14
2	Weight Operation	1145	1125	1120	1055	893	877	838	811	599	535	511	361	137	134

With a total cumulative processing time of 2,982 seconds across all work elements and a proposed target Takt Time ceiling of 1,350 seconds set by management, the theoretical minimum number of workstations is calculated using the following equation:

$$K_{min} = \frac{2,982}{1,350} = 2.208 \approx 3 \text{ Workstations}$$

5.) Allocation of Work Elements to Proposed Workstations

Adhering to the priority ranking guidelines while strictly satisfying the precedence constraints and the requirement that the cumulative station cycle time must not exceed the Takt Time limit (1,350 seconds), the 14 work elements were balanced and allocated across 3 workstations (the actual manual operators). This optimization successfully yielded the final task distribution: Station 1 (Operator 1) accommodates 6 elements with a total duration of 1,051 seconds; Station 2 (Operator 2) accommodates 7 elements with a total duration of 940 seconds; and Station 3 (Operator 3) accommodates 6 elements with a total duration of 992 seconds. The resulting allocation is presented in Table 9.

Table 8. Work Element Allocation

Line Frame Welding MX3W				
Man Power	Process	Time	Line Efficiency	Output / Day (Unit)
MP 1	Sub Assy Middle Frame	1050	94,67%	20
	Sub Assy Front Bracket Leaf Spring			
	Sub Assy Middle Cross Frame			
	Sub Assy Engine Mounting			
	Sub Assy Front Guard LR			
	Sub Assy Bottom Frame L			
MP 2	Sub Assy Bottom Frame R	940		
	Front Assy Main Frame			
	Sub Assy Front Frame			
	Sub Assy Main Rear Frame			
	Assy Main Frame			
	Sub Assy Brake System			
	Top Frame			
MP 3	Top Frame	992		
	Sub Assy Front Frame			
	Sub Assy Top Frame			
	Sub Assy Main Rear Frame			
	Sub Assy Rear Frame			
	Assy Main Frame			

a) Total Waktu

$$Wt = 1050 + 940 + 992 = 2982 \text{ detik}$$

b) Line Efficiency

$$LE = \frac{\sum Ti}{n \times Wsmax} \times 100\% = \frac{2982}{3 \times 1050} \times 100\% = 94,67\%$$

c) Balance Delay

$$BD = 100\% - LE = 100\% - 94.67\% = 5,33\%$$

4. Mapping of the Proposed SWCT, SWC, and Yamazumi Visual Tracking Platforms

The resulting optimized work element combinations were arranged chronologically in the proposed Standardized Work Combination Tables (SWCT) and Standardized Work Charts (SWC) for each individual workstation. This documentation serves as an audit platform to strictly monitor and synchronize manual operator paths with automated robotic welding cycles. Finally, the accumulated station workloads were displayed on floor-level tracking boards utilizing a new stacked Yamazumi Chart to ensure clear process visibility.

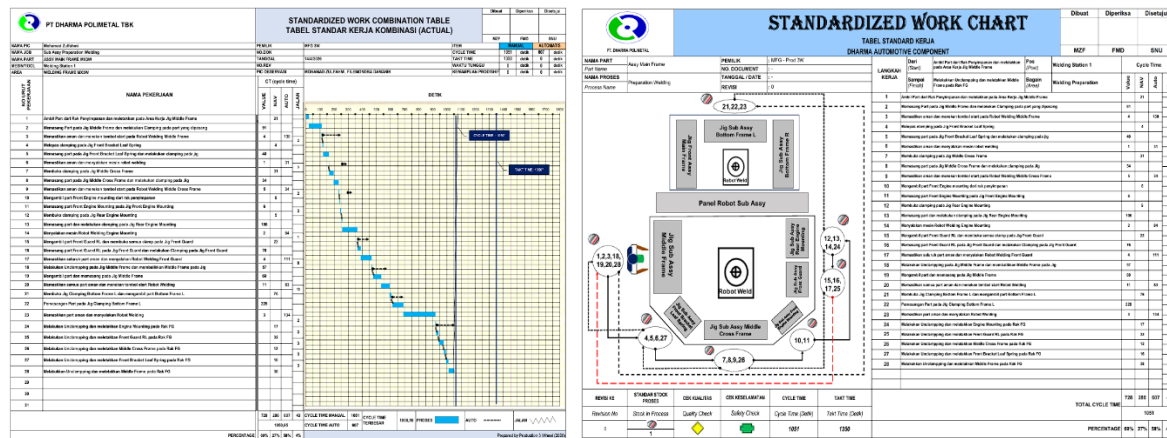


Fig. 6. SWCT & SWC Work Station 1

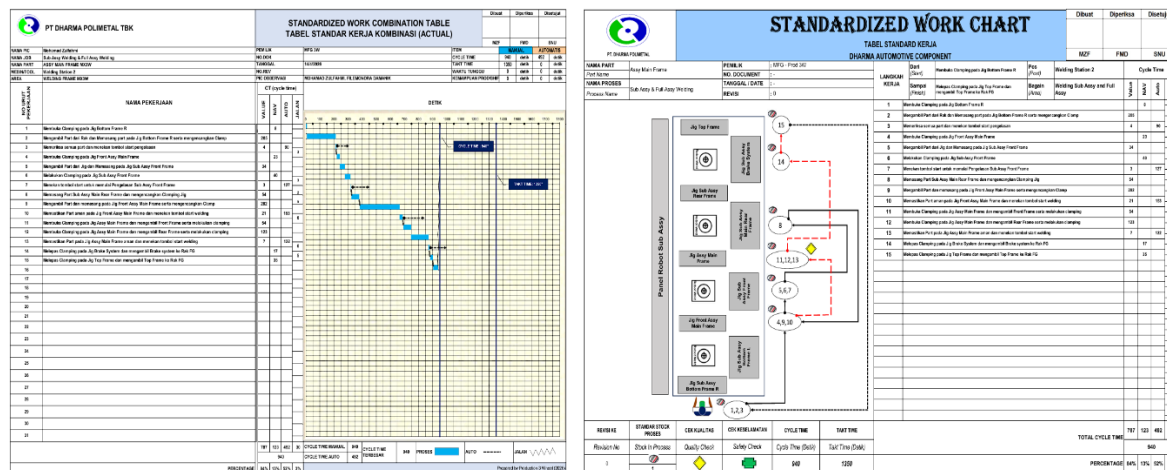


Fig. 7. SWCT & SWC Work Station 2

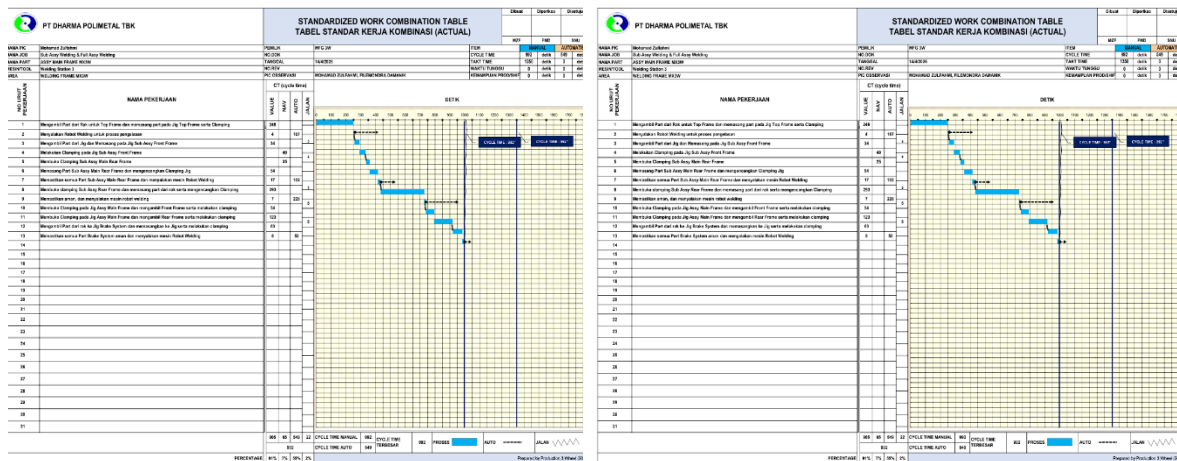


Fig. 8. SWCT & SWC Work Station 3

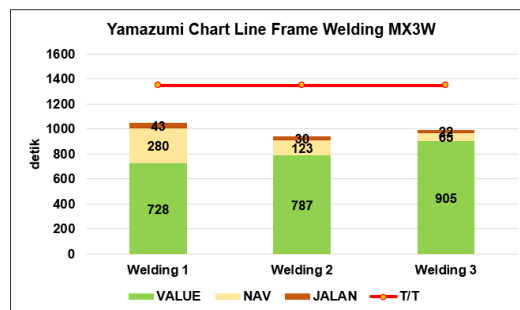


Fig. 9. Yamazumi Chart

3.7 Step 7: Result Evaluation

Practically, this research shows that the application of the Line Balancing method using Ranked Positional Weight (RPW), supported by the standardization of Work Instruction (WI), Combination Standard Work Table (TSKK), and Yamazumi Chart, is capable of increasing the efficiency of the MX3W Frame Welding Line from 54.83% to 94.67% and reducing Balance Delay from 45.17% to 5.33%. The improvement had an impact on the even distribution of workload, reduction in idle time, and an increase in production capacity from 10 units to 20 units per day without adding overtime hours. This substantial throughput expansion was achieved using the identical 3-operator configuration without requiring any overtime labor, yielding an audited Net Quality Income (NQI) financial saving of IDR 4,596,249,600 per year.

These results provide a foundation for the company to increase productivity, meet production targets, and maintain operational stability through the updating of work standards and regular evaluations. Theoretically, the research findings strengthen the application of the RPW-based Line Balancing concept in optimizing the distribution of work elements and demonstrate the importance of integrating actual time data, work standardization, and visualization tools in the production line improvement process. This research also provides empirical contributions regarding the application of the Line Balancing method in the automotive manufacturing industry, particularly in the Frame Welding process, and serves as a reference for future studies to test the application of similar methods in different production lines and operational conditions.

3.8 Step 8: Standardization and Follow-Up

To prevent operational regression and secure the 94.67% line efficiency over time, a strict process standardization protocol was finalized. The newly engineered work instructions (WI) achieving 100% data alignment accuracy, the optimized SWCT/SWC charts, and the live Yamazumi tracking boards were formally authorized and mounted directly at the stations to lock the new method. As a forward-looking follow-up strategy, the plant management approved a horizontal deployment blueprint (*Yokoten*) to replicate this RPW

line balancing framework across adjacent automotive frame lines within the 3-Wheel Manufacturing Department.

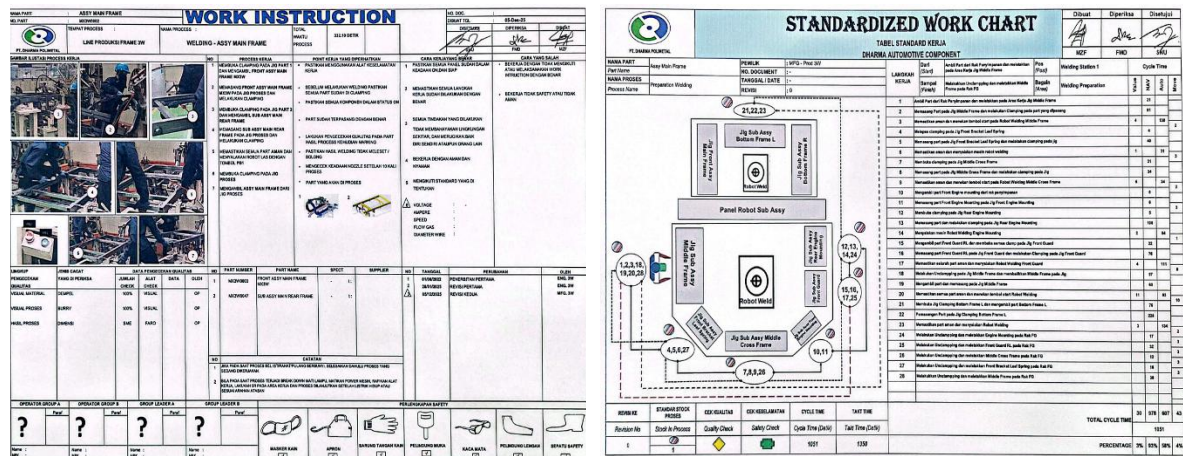


Fig. 10. WI & SWC (Signature)

4. Conclusion

This study successfully resolved the production inefficiencies on the 3W Frame Welding Line at PT X. The application of the Line Balancing method has significantly improved the performance of the production line at PT X. The results of the line-balancing analysis showed an increase in Line Efficiency (LE) from the initial condition of 54.83% to 94.67% in the proposed condition. The achievement of an efficiency of 94.67% has exceeded the research target of 90% as well as the company's minimum standard set at 85%. This research successfully developed a new work standardization document for the MX3W Frame Welding Line. The new work standardization document was developed based on an audit of actual work elements in the latest Work Instruction (WI) document, resulting in 100% accuracy in the cycle-time data. This document is supported by the Combination Standard Work Table (TSKK) and Yamazumi Chart, which transparently map the relationship between operator manual time, machine time, and running time. This implementation successfully eliminated a cycle time data gap of 3,290 seconds, which previously existed between the cycle time in the work standardization document and the actual cycle time.

Acknowledgment

The authors extend their appreciation to the corporate management of PT X for facilitating this industrial internship program, and to the production engineers and operators of the 3-Wheel Division for their data support, technical insights, and collaborative effort throughout this continuous improvement initiative.

Declarations

Author contribution. The contribution or credit of the author must be stated in this section.

Mohamad Zulfahmi: Conceptualization, methodology, data collection, and Data analysis.

Yuliani Fauziah & Filemondra Damanik: Validation, Manuscript review, and editing

Funding statement. No funding agency

Conflict of interest. No conflict of interest

Additional information. No additional information is available for this paper

References

- [1] R. S. Aji and P. E. Widjajanti, "Line Balancing Analysis Using Ranked Positional Weight and Region Approach Method in Nail Production," *J. LA MULTIAPP*, vol. 05, no. 03, pp. 232–244, 2024, doi: 10.37899/journallamultiapp.v5i3.1361.

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- [2] M. Bajomo, A. Ogbeyemi, and W. Hang, "A Systems Dynamics Approach to the Management of Material Procurement for Engineering, Procurement and Construction industry, International Journal of Production Economics," *J. Prod. Econ.*, vol. 244, 2022, doi: <https://doi.org/10.1016/j.ijpe.2021.108390>.
- [3] F. Achmadi, B. Harsanto, and A. Yunani, "Improvement of Assembly Manufacturing Process through Value Stream Mapping and Ranked Positional Weight: An Empirical Evidence from the Defense Industry," 2023, doi: <https://doi.org/10.3390/pr11051334>.
- [4] P. Asih, "Pengukuran Efisiensi Waktu Proses Produksi Pada Setiap Stasiun Kerja Pembuatan Keramik Model Guci Ukuran Tinggi 80 cm . (Studi Kasus Pada Home Industri Jaya Keramik Yogyakarta)," *J. Rekayasa Ind.*, vol. 3, no. 1, pp. 41–50, 2021, doi: <https://doi.org/10.37631/jri.v3i1.290>.
- [5] M. R. Rahmantto and E. P. Widjajati, "Line Balancing Analysis Using Ranked Positional Weight and Region Approach Methods on Broad Plate Production Line," *J. LA MULTIAPP*, vol. 06, no. 01, 2025, doi: [10.37899/journallamultiapp.v6i1.1767](https://doi.org/10.37899/journallamultiapp.v6i1.1767).
- [6] É. L. Luciano, M. T. Okano, R. B. Ribeiro, T. C. F. Rocha, and W. A. D. Chaves, *Implementation of Takt Time in the Development of a New Value Stream Mapping in the Production of Coffee Powder*. Springer International Publishing, 2021. doi: [10.1007/978-3-030-78570-3](https://doi.org/10.1007/978-3-030-78570-3).
- [7] I. Purnamasari and A. S. Cahyana, "LINE BALANCING DENGAN METODE RANKED POSITION WEIGHT (RPW)," *Spektrum Ind.*, vol. 13, no. 2, pp. 115–228, 2015, doi: <https://doi.org/10.12928/si.v13i2.2693>.
- [8] A. B. Sulistyo, "PERENCANAAN LINE BALANCING PROSES PRODUKSI PADA SHEARING LINE PLANT DENGAN MENGGUNAKAN METODE RANK POSITION WEIGHT," *J. Penelit. dan Apl. Sist. dan Tek. Ind.*, vol. XVI, no. 1, pp. 49–60, 2022, doi: <https://doi.org/10.22441/pasti.2022.v16i1.005>.
- [9] M. Afifuddin, "PENERAPAN LINE BALANCING MENGGUNAKAN METODE RANKED POSITION WEIGHT (RPW) UNTUK MENINGKATKAN OUTPUT PRODUKSI PADA HOME INDUSTRI PEMBUATAN SEPATU BOLA," *J. Ind. Eng. Manag.*, vol. 4, no. 1, pp. 40–48, 2019, doi: <http://dx.doi.org/10.33536/jiem.v4i1.287>.
- [10] H. Chang, R. M. Silitonga, Y. Zelita, A. Muna, and Y.-T. Jou, "Application of Ranked Position Weight and Region Approach Method in Overcoming Bottlenecks in Garment Industry," *Res. Synerg. Found.*, vol. 2, no. 1, pp. 23–36, 2022, doi: <https://doi.org/10.31098/cset.v2i1.512>.
- [11] D. Siregar and A. Yasid, "ANALISIS PENINGKATAN KAPASITAS PRODUKSI PADA PROSES PEMBUATAN FRAME MOTOR KLX DENGAN METODE LINE BALANCING DI PT . KMI," *J. Matrik*, vol. XIX, no. 1, pp. 37–48, 2018, doi: [10.30587/matrik.v19i1.580](https://doi.org/10.30587/matrik.v19i1.580).
- [12] Supriyono, D. Suryanto, F. Hendra, and R. Efendi, "LINE BALANCING ANALYSIS BY USED RANK POSITIONAL WEIGHT (RPW) (CASE STUDY : PART BODY S11038Z PROCESS)," *J. Ilm. Tek. Mesin*, vol. 14, no. 2, pp. 123–129, 2020, doi: [10.24853/sintek.14.2.123-129](https://doi.org/10.24853/sintek.14.2.123-129).
- [13] G. Campilho, P. Ferreira, T. Santos, P. Dias, and G. Silva, "Assembly and Improvement of an Assembly Line in the Automotive Industry," *Procedia Manuf.*, vol. 38, no. 2019, pp. 1444–1452, 2020, doi: [10.1016/j.promfg.2020.01.143](https://doi.org/10.1016/j.promfg.2020.01.143).
- [14] A. Mortada and A. Soulhi, "Improvement of Assembly Line Efficiency by Using Lean Manufacturing Tools and Line Balancing Techniques," *Adv. Sci. Technol. Res. J.*, vol. 17, no. 4, pp. 89–109, 2023, doi: <https://doi.org/10.12913/22998624/169257>.
- [15] M. Al Farizi, C. D. Maulana, and J. Purnama, "PENGARUH TIME AND MOTION STUDY TERHADAP PROSES SETTING UNTUK MENINGKATKAN PRODUKTIVITAS DIVISI HPS (Studi kasus PT. XYZ)," vol. 3, no. September, pp. 22–30, 2023.

- [16] M. Fitri, M. Yetrina, Susriyanti, and S. Laurenza, “Optimalisasi Line Balancing Menggunakan Metode Ranked Positional Weight, Moodie Young, dan J-Wagon,” *J. Teknol.*, vol. 13, pp. 74–80, 2023, doi: 10.35134/jitekin.v13i1.103.
- [17] H. Chen, P. Wang, and Q. Ji, “Analysis of the Application Effect of PDCA Cycle Management Combined With Risk Factor Management Nursing for Reducing Infection Rate in Operating Room,” vol. 9, no. March, pp. 1–7, 2022, doi: 10.3389/fsurg.2022.837014.
- [18] D. Sjarifudin and H. Kurnia, “The PDCA Approach with Seven Quality Tools for Quality Improvement Men ’ s Formal Jackets in Indonesia Garment Industry,” vol. 24, no. 2, pp. 159–176, 2022, doi: 10.32734/jsti.v24i2.7711.
- [19] I. K. Sriwana, A. Jatikusumo, N. Erni, A. Suwandi, and T. Rachman, “Usulan Perbaikan Keseimbangan Lini di PT . XYZ Menggunakan Moodie-Young dan Ranked Positional Weight untuk Meningkatkan Efisiensi Lini Produksi,” *J. Metris*, vol. 22, pp. 82–91, 2021.