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Reduction Coal Hauling Tonnage Losses using Weigh-In-Motion Truck Scale at PT Borneo Indobara

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ABSTRACT
The persistence of manual weighing practices in coal transportation has led to significant revenue losses at PT Borneo Indobara, with a recorded discrepancy of -1.218% in coal tonnage reconciliation during Q4 2023—exceeding the company's ±0.5% threshold. This research aims to identify the root cause of this issue, evaluate alternative solutions, and propose a strategic implementation plan to eliminate manual weighing. Employing the Current Reality Tree (CRT) method, the study found that the core issue was the absence of prior investigation into weighing alternatives. Using both primary (interviews, FGDs, observations) and secondary data (company reports, standards), three alternatives—Weighbridge, Low-Speed Weigh-in-Motion (LS-WIM), and High-Speed Weigh-in-Motion (HS-WIM)—were assessed using the Analytic Hierarchy Process (AHP) based on accuracy, productivity, and investment cost. The LS-WIM alternative emerged as the most optimal, scoring 0.37, due to its high productivity and moderate cost, despite slightly lower accuracy. Implementation is planned through a structured PDCA-based approach, covering proposal development, tendering, construction, and commissioning. With LS-WIM's expected accuracy of ±2%, the study projects a reversal of revenue loss into a gain of approximately USD 314,963.27, illustrating the business value of replacing manual weighing. This research contributes a novel integration of CRT and AHP methodologies in the coal logistics context and provides an actionable, stakeholder-informed roadmap for technology implementation. Future studies are encouraged to explore long-term performance, hybrid system integration, and cross-industry applicability of weigh-in-motion technologies.

Keywords: weighbridge, LS-WIM, CRT, AHP, accuracy, productivity

INTRODUCTION
Indonesia ranks among the top three coal producers globally, following China and India, as illustrated in Figure 1. Over time, Indonesia's coal production has seen an upward trend, as shown in Figure 2, with a projected output of 735 million tons by 2025 (IEC, Coal 2024), despite a decline in coal prices, depicted in Figure 3. The IEC forecasts a reduction in Indonesian coal production to 731 million tons by 2027, primarily due to China, the largest global importer, continuing to diversify its energy sector from 2024 onwards by advancing nuclear plant construction and significantly expanding solar PV and wind capacities. Given the current global coal trade dynamics, where demand is expected to remain relatively stable until 2027 while prices are slightly decreasing, PT Borneo Indobara (BIB) still has the potential to produce 54 million tons over the next three years, as outlined in Figure 4.

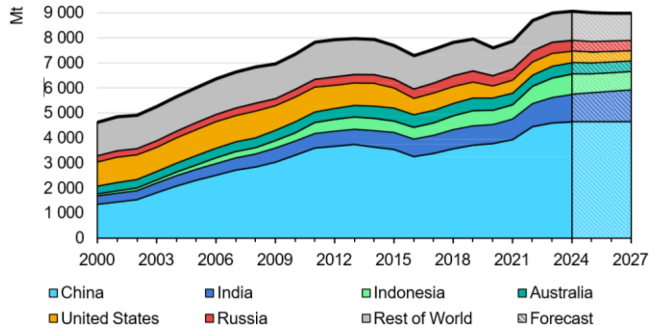

Figure 1 Global Coal Production, Actual and Forecast

Figure 2. Indonesian Coal Production

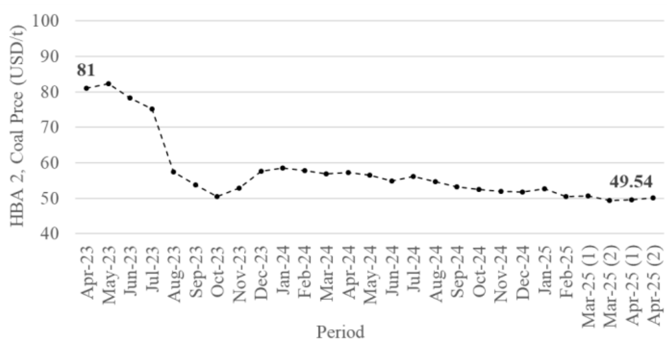

Figure 3. Indonesian Benchmark Coal Price of GAR 4.100 kcal/kg

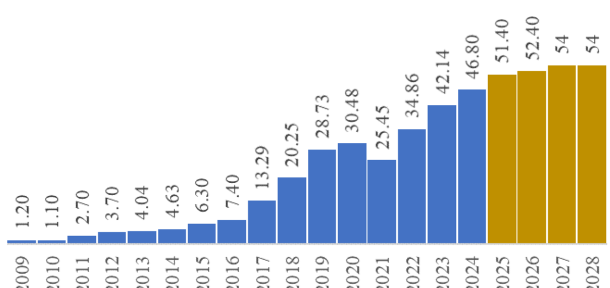

Figure 4. Company's Coal Production and Plan (Million Ton)

In order to ensure the accuracy of the coal tonnage data, the company conducts quarterly reconciling the coal tonnage dispatched to the port with the weighing data, the tonnage recorded in the port stockpile derived from a topographical survey, and the shipping tonnage. The reconciliation report for the 4th quarter of 2023, which calculates the balance of coal tonnage for the period from September 27 to December 12, indicates a discrepancy of minus 132,695.033 tons in the port's stockpile, representing minus 1.218% of the total coal production of 10,894,612.180 tons during that timeframe. This report clarifies that the discrepancy arises from the fact that not all coal hauling trucks are weighed using the weighbridge, it means manual weighing (Company's Report, December 2023).

Manual weighing is conducted in two methods: (1) for trucks that are below the weighbridge's capacity, the average of the last 10 weighbridge measurements is utilized to determine the tonnage for each truck; (2) For trucks exceeding the weighbridge's capacity, samples from 10 trucks of the same type are transferred to a smaller truck and weighed on the weighbridge, with the average of these 10 trucks serving as the basis for tonnage calculation.

Evidence indicates that when weighing is performed using a weighbridge, the truck load is at full capacity, whereas manual weighing often results in incomplete loads, as illustrated in Figure 5 below. Enforcement measures have been implemented by penalizing coal hauling contractors through reductions in the tonnage of coal transported to the port. With 11 contractors operating 874 trucks and making approximately 4,500 trips, transporting 177,000 tons per day, these enforcement efforts are challenging and do not fully resolve the issue, thus highlighting the need to address the manual weighing process as a significant business concern.

Figure 5. Truck is not Fully Loaded when Manual Weighing

The aforementioned circumstances, where the discrepancy between the actual tonnage and the measured weight is a negative 1.218%, have led to excessive payments to contractors whose compensation is determined by coal tonnage. This includes: (1) the coal hauling contractor responsible for transporting coal from the mine to the port over a distance of 32 kilometers; (2) the road maintenance contractor tasked with maintaining the coal hauling road along the same 32 kilometers; (3) the coal loading contractors who load coal onto hauling trucks at the mine's stockpile; (4) the lease for a 12-kilometer haul road utilized by the company for coal transportation from the mine to the port, owned by another party; (5) the lease for an underpass that crosses a provincial road, also owned by another party, used by the company for coal transport from the mine to the port. The potential revenue loss for the company due to these overpayments is illustrated in Table 1 below.

Table 1. Loss of Company's Revenue due to Manual Weighing

No	Descriptions	Unit	Rate (USD/ton)	Value
A	Coal Tonnage :			
1	Current Condition, Tonnage Loss (Reconciliation Report, Q4 2023)	%		(1.218)
2	Allowed Tonnage Loss (SOP of Stockpile Management)	%		(0.50)
3	Loss Difference	%		(0.718)
4	Coal Production (Reconciliation Report, Q4 2023)	Ton		10,894,612.18
		Coal Tonnage (Loss) :		(78,223.32)
B	Company's Income for Payment of :			
1	Coal Hauling Contractors, 32 km	USD	2.57	(201,033.93)
2	Road Maintenance Contractor, 32 km	USD	0.19	(14,862.43)
3	Loading Coal to Truck at ROM	USD	0.30	(23,467.00)
4	Haul Road Lease from other Party	USD	0.77	(60,231.96)
5	Underpass Lease from other Party	USD	0.30	(23,467.00)
	Total Company's Revenue (Loss), USD :			(323,062.32)

According to the table, the negative difference of 1.218% exceeds the company's maximum allowable limit of ±0.5%, resulting in a coal tonnage loss of 1.218% - 0.5% = 0.718% negative. When applying the contractual work price rate with the contractors and factoring in the coal tonnage loss, the company's revenue has decreased by 323,062.32 USD during the same period. Given the significant impact of the coal tonnage discrepancy, the author aims to improve the negative difference of 1.218% to a maximum of ±0.5%, as stipulated in the company's Standard Operating Procedure (SOP) for stockpile management.

This research aims to address the persistent business challenge of manual coal weighing at PT Borneo Indobara by identifying its root cause, exploring viable solutions, and analyzing implementation strategies through a combination of the Current Reality Tree (CRT) and Analytic Hierarchy Process (AHP) methodologies. The novelty of this study lies in its integrative approach, combining CRT for root cause analysis and AHP for multi-criteria decision-making, which led to the selection and justification of Low-Speed Weigh-in-Motion (LS-WIM) technology as the optimal solution. Unlike prior studies that focused solely on weighing system accuracy and calibration, this research includes a financial quantification of potential revenue losses and gains, thus emphasizing real business and operational impacts (Brzozowski et al., 2023; Burnos et al., 2018; Hernandez, 2017; Munum Masud & Haider, 2021; Ryguła et al., 2020; Yanik & Higgins, 2019; Yu et al., 2016). Additionally, the study applies a PDCA-based implementation strategy, which is rarely used in similar coal logistics research, and involves five cross-functional stakeholders in determining AHP-based priorities, providing a participatory and contextualized decision-making process (Arredondo-Soto et al., 2021; Kanbanize, 2018; Nguyen et al., 2020b, 2020a; Patel & Deshpande, 2017). The research is limited by the use of weighing equipment from

Intercomp Company and Mettler Toledo for research purposes only (not commercial comparison), temporally specific cost estimates, exclusion of maintenance costs, and a fixed exchange rate of 1 USD = 16,850 IDR. Altogether, this study offers a novel, actionable framework for enhancing weighing system efficiency and financial accountability in Indonesia's coal industry.

RESEARCH METHODS

A conceptual framework is used by the author to organize and structure research by outlining the relationships between key concepts or variables within a study. It helps researchers define the problem, guide their research direction, and ensure coherence throughout the study. Essentially, it acts as a blueprint for research, connecting theories, assumptions, and concepts to provide a clear roadmap for understanding a research question.

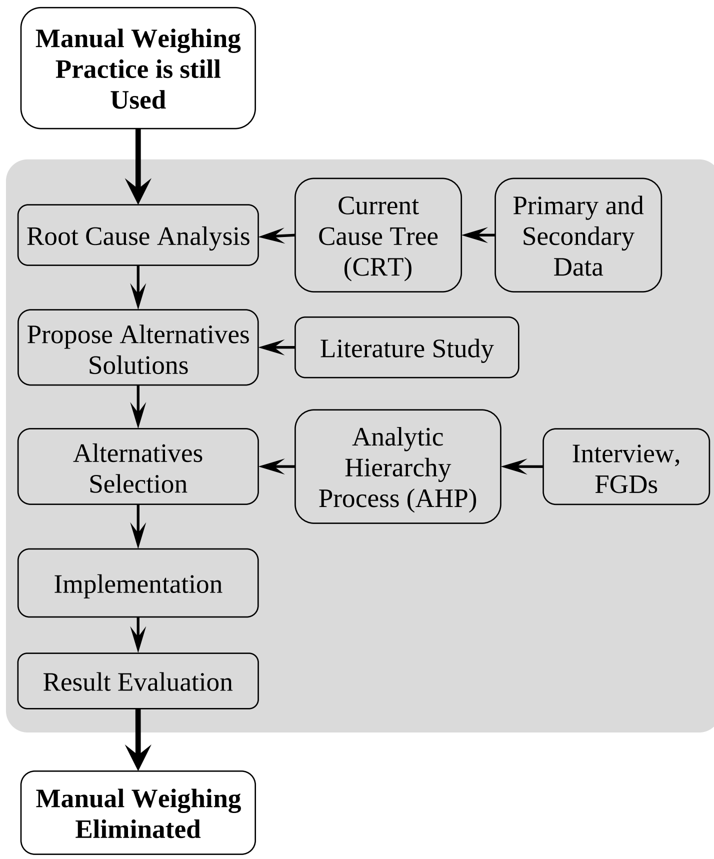

Figure 6. Conceptual Framework of this Research

Figure 6 illustrates that manual weighing continues to be utilized in contemporary practices. To address this issue, a comprehensive business solution is required, which encompasses the following components: (a) Root Cause Analysis, which is essential for identifying the reasons behind the ongoing use of manual weighing by examining both primary and secondary data, (b) Alternative Proposal, which must be developed once the root cause is established, providing various options for addressing the business challenge. This proposal will be informed by a literature review pertinent to the issue at hand. (c) Analysis, where the alternative proposals will be evaluated using the Analytic Hierarchy Process (AHP), incorporating feedback from stakeholders involved in the operations to determine the most suitable alternative for the company's needs, (d) Implementation, which involves executing the chosen business solution derived from the prior analysis, (e) Justification, which entails assessing the outcomes of the implementation. If the evaluation indicates success, the business issue will be resolved, leading to the elimination of manual weighing practices.

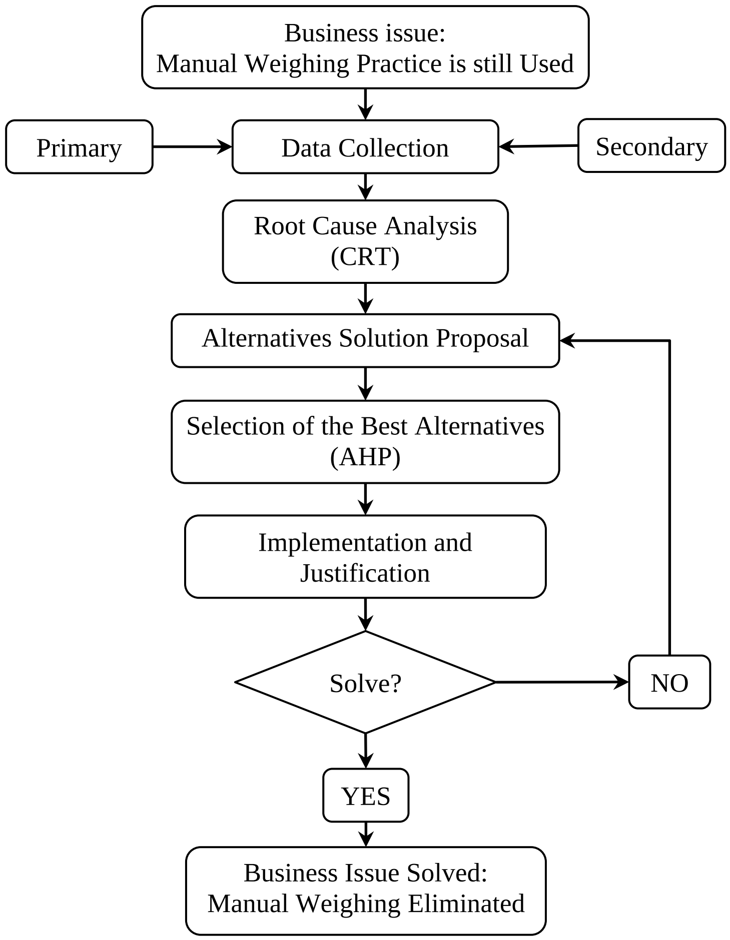

Figure 7. **Research Design Diagram**

This research follows a structured process, starting with identifying business problems, collecting both primary and secondary data, and analyzing root causes using the Current Reality Tree (CRT) to understand the issues. Based on this analysis, alternative solutions are proposed and evaluated using the Analytic Hierarchy Process (AHP) to select the best option. The best alternative is then implemented, and if it resolves the business issue, the research concludes; otherwise, the solution is reevaluated. The research, conducted from January 10 to April 25, 2025, is currently in the stage of submitting an investment proposal to management. Data collection is divided into primary and secondary sources, as illustrated in Figure 8.

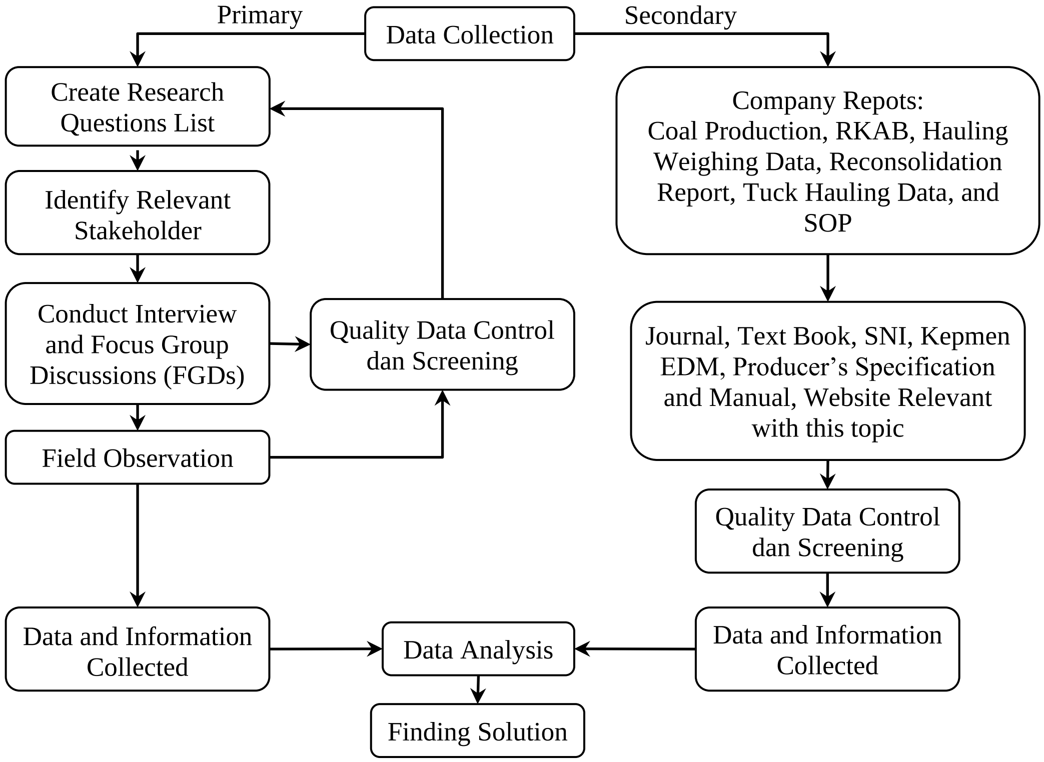

Figure 8. **Data Collection Method Diagram**

Primary data for this research are gathered directly from data sources in the field through interviews, Focus Group Discussions (FGDs), and field observations of weighing and hauling operations. The collection of primary data is crucial to understanding the business issue at hand, and the selection of relevant stakeholders ensures the accuracy of the data. Stakeholders involved include the Business Unit Head, Strategic Long-Term Planning & Optimization Department Head, Coal Chain Coordinator & Head of CPP Operations Department Head, ROM and Hauling Department Head, Road Maintenance Department Head, and Infrastructure Project and Maintenance Department Head. Each of these stakeholders has direct responsibility over different aspects of the coal mining and transportation process, ensuring that the data collected is comprehensive and reflective of the business operations.

FGDs are conducted to explore participants' views and experiences related to the research questions, emphasizing group interaction and dynamics in generating insights. A moderator guides the discussions to maintain focus and relevance. Prior to the interviews and FGDs, a list of research questions is prepared to ensure the sessions are productive and aligned with the study's objectives. Table 4 provides details of the stakeholders involved and the topics discussed during the interviews and FGDs, highlighting the direct relationship between each stakeholder and the business issue under investigation.

Table 4. **Interview and FGDs**

Respondent	**Person**	**Method**	**Topics**
Business Unit Head (BU Head)	1	Direct Interview	• Response regarding the reconcile report period of 27 September to 12 December 2023, which stated

			that there was a difference in coal tonnage of 1.218% (loss) due to manual weighing. • Input of solutions to eliminate manual weighing practice
Strategic Long-Term Planning & Optimization Department Head (SPO)	1	FGDs	• How much coal production target has been planned by management for the next 3 years, 2026 to 2026 • The current mining process flow
Coal Chain Coordinator & Head of CPP Operations Department Head (CCC)	1	FGDs	• The weighing process currently being carried out • What obstacles are currently being faced, and what are the expectations so that weighing can meet coal production targets • What is the ideal scale accuracy for coal hauling operations in the company • Input of solutions to eliminate manual weighing practice
ROM and Hauling Department Head (CHR)	1	FGDs	• How many trucks are currently operating, dimensions and payload. • Are there any plans to increase the truck population? • What obstacles are currently being faced, and what are the expectations so that coal hauling can meet coal production targets • Input of solutions to eliminate manual weighing practice
Road Maintenance Department Head (RM)	1	FGDs	• Length of coal hauling road maintenance carried out by road maintenance contractors
Infrastructure Project & Maintenance Department Head (IPM)	1	FGDs	• Current condition of static scales and assess whether these scales can still be improved to meet coal transportation targets. • Input of solutions to eliminate manual weighing practice • Availability of location for placement of new truck scales

Field observation was conducted by the researchers to gather actual field data regarding weighbridge conditions, weighing practices, scale dimensions and capacity, weighing cycle time, as well as the dimensions and Gross Vehicle Weight (GVW) of trucks. This data was essential in understanding the current practices and performance of the coal hauling and weighing operations. In addition to primary data, secondary data was collected from non-confidential company documents and public sources. Company documents included coal production data, the Annual Work Plan and Budget (RKAB) 2024 – 2026, coal hauling weighing records, shipping records, port stockpile measurements, and truck specifications. Public documents included journals, textbooks, relevant standards such as the Indonesian National Standard (SNI), and the Ministerial Decree on Good Mining Practices (Kepmen ESDM No 1827 K/30/MEM/2018).

For data analysis, both qualitative and quantitative methods were employed. Qualitative Data Analysis was used to examine non-numerical data from interviews, FGDs, field observations, and root cause analysis. The author utilized the Current Reality Tree (CRT) to trace the root cause of business issues, as it provides a visual representation to identify conflicts and underlying causes. Stakeholders were involved in answering specific questions related to manual weighing, the number of weighbridges, and alternative weighing methods. Quantitative analysis was applied to propose alternative truck scales and calculate the Analytical Hierarchy Process (AHP). In determining the criteria for evaluating alternatives, stakeholders agreed on three key factors: accuracy, productivity, and investment costs.

RESULTS AND DISCUSSION

1. Root Cause Analysis

Manual weighing is a business problem and needs to be resolved immediately (Batilas et al., 2017; Chyzhykov et al., 2023; Loga & Mikulski, 2016). This is because it has an impact on the credibility and accountability of the company, the accuracy of payments for activities related to coal hauling tonnage such as payments to coal hauling contractors, to road maintenance contractors, to coal loading contractors at Run of Mine (ROM) or known as stockpiles in mines, and to road and underpass leases from other parties. The development of the root of this problem involves stakeholders involved in this coal operation, by asking questions as mentioned in the Qualitative Data Analysis of the Research Methodology.

In Figure 9, the UDE is Manual weighing practice is still used. The cause of this UDE is weighbridges are currently not enough in number to weigh all trucks as the first root cause, the causes of this first root cause are two: Low productivity as the second root cause and there is no addition of weighbridge yet as the third root cause. The second root cause is caused by trucks must stop when being weighed as the fourth root cause, this fourth root cause can occur because dynamic weighing is assumed not suitable for trade as the fifth root cause, this fifth root cause is caused by alternative weighing has never been studied as the sixth root cause. The third root cause is caused by there is no additional space to place new weighbridge as the seventh root cause, the seventh root cause is caused by the sixth root cause. Since the second and third root causes are caused by the sixth root cause, then the sixth root cause which is Alternative weighing has never been studied is the core problem that causes UDE to occur.

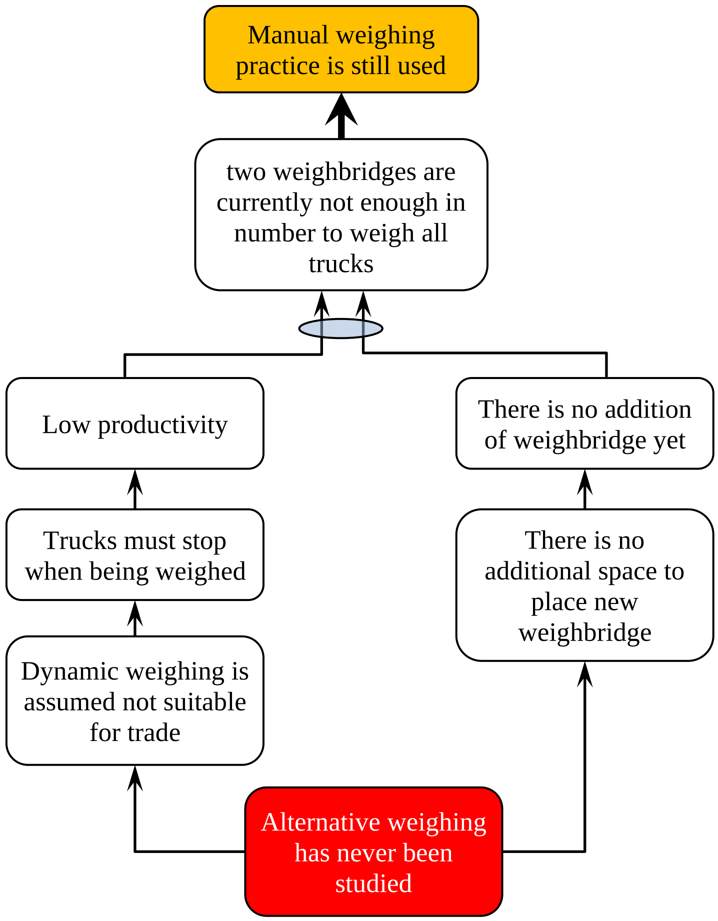

Figure 9. Tracing Root Cause using CRT

2. Alternative Weighing Proposal

The author proposes 3 weighing alternatives to be analyzed using AHP to obtain the best alternative as a business solution:

a. Alternative 1: Static truck scales or known as weighbridges, with dimensions that can weigh all dimensions and weight of coal hauling trucks.
b. Alternative 2: Low Speed Weigh-in-Motion (LS-WIM) truck scales, which can weigh all dimensions and weight of coal hauling trucks.
c. Alternative 3: High Speed Weigh-in-Motion (HS-WIM) truck scales, which can weigh all dimensions and weight of coal hauling trucks.

The selection of the three alternatives above is based on the fact that all three have the same capability in weighing trucks with large dimensions and large truck loads, the differences between the three are only in: accuracy, productivity and investment costs, details of each type of scale can be seen in Chapter 3 and all three are types of scales commonly used in international logistics work, and there are supplier and installer representatives available in Indonesia for the three types of scales above.

Alternative 1: Static Truck Scales / Weighbridge

To calculate the productivity of weighing, it is necessary to know the following:

a. type of truck used in the calculation, dimensions of the truck, speed of the truck, safe distance between trucks during weighing, idle time during weighing.
b. from the parameters above, the cycle time for each weighing can be obtained, and how many trucks can be weighed in one hour of cycle time
c. determine the payload of the truck, thus obtaining the tonnage in one cycle hour or productivity per hour, in tons / hour
d. assumed effective weighing working hours of 5500 hours, this number of effective hours has been assumed with a reduction in working hours for maintenance, repairs, company holidays, and other unpredictable events
e. from effective working hours per year and productivity per hour, annual productivity is obtained, tons / year

Similar way for calculating productivity for other alternative 2 and 3, in Table 5 below is the calculation of productivity of Weighbridge.

Table 5. Productivity of Static Truck Scale, VTS420 Mettler Toledo USA

Truck length, rounded	40	m
Truck speed passing through weighbridge, recommended	5	km/h
Clear safe distance between trucks, recommended	20	m
Time of truck stop when taking weight	1	minute
Cycle time, thus	1.72	minute
Frequency / hour	35	trucks
Payload, use Double SDT 90 Quadaxle	165.6	tons
Capacity per hour	5,796	tons
Capacity per year, assume 5500 effective working hours, thus	32	million tons
Coal Production Target	54	million tons
Number of Truck Scale Required:	2	units

(Source : Author's Estimation)

The calculation of investment cost is based on the common unit price of work at the project site and the estimated cost from the supplier and applicator of the weighing. Similar way for calculating investment costs for other alternative 2 and 3.

Table 6. Investment Cost of Static Truck Scale, VTS420 Mettler Toledo USA

No	Descriptions	Cost (USD)
1	Concrete Foundation, 4.5 m x 50 m x 0.35 m, K350	35,051.93
2	Scale Platform, Load Cells, System	272,997.03
3	Scale House	29.67
	Total:	308,078.63
	Total, 2 Units:	616,157.26

(*Source*: Author's Estimation)

Alternative 2: Low Speed Weigh-in-Motion (LS-WIM) Truck Scale

Table 7. Productivity of LS-WIM, Intercomp Company USA

Truck length, rounded	40	m
Truck speed passing through weighbridge, recommended	10	km/h
Clear safe distance between trucks, recommended	30	m
Time of truck stop when taking weight	–	minute
Cycle time, thus	0.42	minute
Frequency / hour	143	trucks
Payload, use Double SDT 90 Quadaxle	165.6	tons
Capacity per hour	23,680.80	tons
Capacity per year, assume 5500 effective working hours, thus	130	million tons
Coal Production Target	54	million tons
Number of Truck Scale Required:	1	unit

(*Source* : Author's Estimation)

Table 8. Investment Cost of LS-WIM, Intercomp Company USA

No	Descriptions	Cost (USD)
1	Concrete Foundation, 4.5 m x 100 m x 0.3 m, K500	76,112.76
2	LS-WIM, System	105,549.73
3	Scale House	29.67
	Total:	181,692.16

(Source : Author's Estimation)

Alternative 3: High Speed Weigh-in-Motion (HS-WIM) Truck Scales

Table 9. Productivity of HS-WIM, Intercomp Company USA

Truck length, rounded	40	m
Truck speed passing through weighbridge, recommended	15	km/h
Clear safe distance between trucks, recommended	30	m
Time of truck stop when taking weight	–	minute
Cycle time, thus	0.28	minute
Frequency / hour	214	trucks
Payload, use Double SDT 90 Quadaxle	165.6	tons
Capacity per hour	35,438	tons
Capacity per year, assume 5500 effective working hours, thus	195	million tons
Coal Production Target	54	million tons
Number of Truck Scale Required:	1	unit

(*Source* : Author's Estimation)

Table 10. Investment Cost of of HS-WIM, Intercomp Company USA

No	Descriptions	Cost (USD)
A	HS-WIM, Intercomp Company	
1	Concrete Foundation, 4.5 m x 100 m x 0.3 m, K500	76,112.76
2	HS-WIM, System	216,528.19
3	Scale House	29.67
B	Static Truck Scale, ZCS-25, 3 m x 12 m, Mettler Toledo	
1	Concrete Foundation, 4.5 m x 18 m x 0.35 m, K350	12.64
2	Scale Platform, Load Cells, System	50.45
3	Scale House	14.84
	Total :	292,748.55

(*Source* : Author's Estimation)

Alternatives Summary

Table 11. Summary of Proposed Alternative Solution

Descriptions	Accuracy (% ±)	Productivity / Year (Million Tons)	Investment Cost (USD)	Numbers of Required
Weighbridge	0.1	64	616,157.26	2
LS-WIM Truck Scale	1-2	130	181,692.16	1
HS-WIM Truck Scale	2-3	195	292,748.55	1

3. Solution and Proposed Implementation Plan

Selection of Proposed Alternative Solution

The author uses the Analytic Hierarchy Process (AHP) as a tool to obtain the best alternative from the 3 alternatives proposed by the author based on previous interviews and FDG. Here are 3 criteria resulting from discussions with stakeholders to be analyzed:

a. Accuracy, weighing accuracy
b. Productivity, how much coal tonnage per hour can be weighed,
c. Investment, investment required to build this scale,

The three criteria above will be combined with 3 weighing alternatives to obtain truck scales that meet the expectations of stakeholders:

a. Alternative 1, Weighbridge
b. Alternative 2, LS-WIM
c. Alternative 3, HS-WIM

Figure 10 below provides an overview of the AHP process in determining the best alternative.

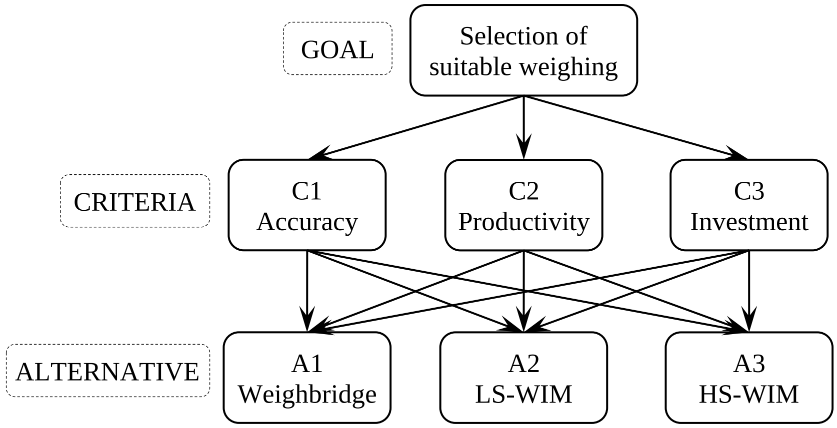

Figure 10. AHP Process Diagram

Priority Stakeholder's Criteria

For simplicity, name of stakeholders is coded as Table 12 below.

Table 12. Stakeholders Coding for Simplicity

Stakeholder Name	**Business Unit Head (BU Head)**	**Strategic Long-Term Planning & Optimization Department Head (SPO)**	**Coal Chain Coordinator & Head of CPP Operations Department Head (CCC)**	**ROM and Hauling Department Head (CHR)**	**Road Maintenance Department Head (RM)**
Stakeholder Code	S1	S2	S3	S4	S5

Each Stakeholder did judgment as Table 13 below, what more importance on each pairwise criteria.

Table 13. **Stakeholder's Criteria Pairwise Comparisons**

Stakeholder	**Pairwise Comparison**										
S1	C1	9	7	5	3	**1**√	3	5	7	9	C2
	C2	9	7	5	3	1	**3**√	5	7	9	C3
	C3	9	7	5	3	1	**3**√	5	7	9	C1
S2	C1	9	7	5	3	**1**√	3	5	7	9	C2
	C2	9	7	5	**3**√	1	3	5	7	9	C3
	C3	9	7	5	3	1	3	**5**√	7	9	C1
S3	C1	9	7	5	3	**1**√	3	5	7	9	C2
	C2	9	**7**√	5	3	1	3	5	7	9	C3
	C3	9	7	5	3	1	3	5	7	**9**√	C1
S4	C1	9	7	5	3	**1**√	3	5	7	9	C2
	C2	9	**7**√	5	3	1	3	5	7	9	C3
	C3	9	7	5	3	**1**√	3	5	7	9	C1

	C1	9	7	5	3	**1**√	3	5	7	9	C2
S5	C2	9	7	5	**3**√	1	3	5	7	9	C3
	C3	9	7	5	3	1	3	**5**√	7	9	C1

Table 14. **Stakeholder's Matrix of Criteria and Criteria Priority**

Stakeholder's Matrix of Criteria				Stakeholder's Criteria Priority							
S1	C1	C2	C3	C1	C2	C3	Eigen	Priority	λmax	CI	CR
C1	**1**	1.00	3.00	**0.43**	**0.43**	**0.43**	**1.29**	**0.43**	**3.00**	**0.00**	0.00
C2	1.00	1	3.00	0.43	0.43	0.43	1.29	**0.43**			
C3	0.33	0.33	1	0.14	0.14	0.14	0.43	**0.14**			
Total	**2.33**	**2.33**	**7.00**	1	1	1		1			
S2	C1	C2	C3	C1	C2	C3	Eigen	Priority	λmax	CI	CR
C1	1	1.00	5.00	0.45	0.43	0.56	1.44	**0.48**	3.04	0.02	0.03
C2	1.00	1	3.00	0.45	0.43	0.33	1.22	0.41			
C3	0.20	0.33	1	0.09	0.14	0.11	0.34	0.11			
Total	2.20	2.33	9.00	1	1	1		1			
S3	C1	C2	C3	C1	C2	C3	Eigen	Priority	λmax	CI	CR
C1	1	1.00	9.00	0.47	0.47	0.53	1.47	**0.49**	3.01	0.00	0.01
C2	1.00	1	7.00	0.47	0.47	0.41	1.35	0.45			
C3	0.11	0.14	1	0.05	0.07	0.06	0.18	0.06			
Total	2.11	2.14	17.00	1	1	1		1			
S4	C1	C2	C3	C1	C2	C3	Eigen	Priority	□max	CI	CR
C1	1	0.33	3.00	0.23	0.22	0.69	1.14	**0.38**	3.01	0.00	0.01
C2	3.00	1	0.33	0.69	0.65	0.08	1.42	0.47			
C3	0.33	0.20	1	0.08	0.13	0.23	0.44	0.15			
Total	4.33	1.53	4.33	1	1	1		1			
S5	C1	C2	C3	C1	C2	C3	Eigen	Priority	λmax	CI	CR
C1	1	1.00	5.00	0.45	0.43	0.56	1.44	**0.48**	3.04	0.02	0.03
C2	1.00	1	3.00	0.45	0.43	0.33	1.22	0.41			
C3	0.20	0.33	1	0.09	0.14	0.11	0.34	0.11			
Total	2.20	2.33	9.00	1	1	1		1			

Explanation for Table 14 above:

Weights of the elements is from: 1/2.33 = 0.43, total of weight in one column must be 1, similar way for other element weightings

Eigen is from: 0.43+0.43+0.43 = 1.29, similar way for other eigen value

Priority value is from: eigen value / number of elements, m = 1.29 / 3 = 0.43, total of weight in one column must be 1, similar way for other priority

λ_{max} is from: 0.43×0.43 + 0.14×2.33 + 2.33×7.00 = 3.00, similar way for other λ_{max}

Consistency Index, CI = (λ_{max} – m) / (m – 1) = (3 – 3) / (3 – 1) = 0, similar way for other CI

Random Consistency, RC, for m = 3, RC = 0.58

Consistency Ratio, CR = CI / CR = 0 / 0.58 = 0, CR must be less than 0.1 and not negative, similar way for another CR then average criteria from five stakeholder, thus, see Table 15.

Table 15. Average of Stakeholder's Criteria

Criteria	Average	Rank
C1	**0.45**	1
C2	**0.43**	2
C3	**0.12**	3
Total	1	

Explanation for Table 15 above:
Average criteria C1 is from: (0.43 + 0.48 + 0.49 + 0.38 + 0.48) / 5 = 0.45, total of all average criteria in one column must be 1, similar way for other average criteria.

Ranking of Alternatives

Judgement this alternative pairwise is based on studied that outlined on previous sub chapter: accuracy, productivity, and investment of each alternative.

Table 16. Alternatives Pairwise Comparisons

Criteria	Pairwise comparison										
C1	A1	9	7	5	**3**√	1	3	5	7	9	A2
	A2	9	7	5	**3**√	1	3	5	7	9	A3
	A3	9	7	5	3	1	3	**5**√	7	9	A1
C2	A1	9	7	5	3	1	**3**√	5	7	9	A2
	A2	9	7	5	3	**1**√	3	5	7	9	A3
	A3	9	7	**5**√	3	1	3	5	7	9	A1
C3	A1	9	7	5	3	1	3	5	7	**9**√	A2
	A2	9	7	5	**3**√	1	3	5	7	9	A3
	A3	9	7	**5**√	3	1	3	5	7	9	A1

Table 17. Alternative Priority

C1	A1	A2	A3	A1	A2	A3	Eigen	Priority	λmax	CI	CR
A1	1	3.00	5.00	0.65	0.69	0.56	1.90	**0.63**	3.06	0.03	0.05
A2	0.33	1	3.00	0.22	0.23	0.33	0.78	0.26			
A3	0.20	0.33	1	0.13	0.08	0.11	0.32	0.11			
Total	1.53	4.33	9.00	1	1	1		1			
C2	A1	A2	A3	A1	A2	A3	Eigen	Priority	λmax	CI	CR
A1	1	0.33	0.20	0.11	0.14	0.09	0.34	**0.11**	3.04	0.02	0.03
A2	3.00	1	1.00	0.33	0.43	0.45	1.22	0.41			
A3	5.00	1.00	1	0.56	0.43	0.45	1.44	0.48			
Total	9.00	2.33	2.20	1	1	1		1			
C3	A1	A2	A3	A1	A2	A3	Eigen	Priority	λmax	CI	CR
A1	1	0.11	0.20	0.07	0.08	0.05	0.19	**0.06**	3.05	0.02	0.04
A2	9.00	1	3.00	0.60	0.69	0.71	2.01	0.67			
A3	5.00	0.33	1	0.33	0.23	0.24	0.80	0.27			
Total	15.00	1.44	4.20	1	1	1		1			

Table 18. Combination Alternatives with Criteria

	C1	C2	C3	Total	Rank
A1	**0.29**	**0.05**	**0.01**	**0.34**	2
A2	0.12	0.18	0.08	0.37	1
A3	0.05	0.21	0.03	0.29	3
Total				1	

Explanation for Table 18 above:
Combination alternative A1 with average criteria C1 is from: 0.45 × 0.63 = 0.29
Combination alternative A1 with average criteria C2 is from: 0.43 × 0.11 = 0.05
Combination alternative A1 with average criteria C3 is from: 0.12 × 0.06 = 0.01, thus total is from 0.29 + 0.05 + 0.01 = 0.34, similar way for other alternative.
From three alternatives above, alternative A1 (LS-WIM) has the highest score followed by A1 and A4, so A1 is the best choice for solution.

Potential Revenue After LS-WIM Implementation

The business issue outlined in Chapter I highlighted that manual weighing led to a revenue loss of 323,062.32 USD for the company. However, with the implantation of LS-WIM with accuracy expected of -2% as specification of LS-WIM, this loss was transformed into a profit of 314,963.27 USD. For a comprehensive breakdown of the revenue calculations, please refer to Table 19 below.

Table 19. Potential Company's Revenue after LS-WIM Implementation

No	Descriptions	Unit	Rate (USD/ton)	Value
A	Coal Tonnage:			
1	LS-WIM Accuracy Expectation	%		0.2
2	Allowed Tonnage Loss (SOP of Stockpile Management)	%		(0.50)
3	Loss Difference	%		0.7
4	Coal Production (Reconciliation Report, Q4 2023)	Ton		10,894,612.18
	Coal Tonnage Difference (Gain):			**76,262.29**
B	Company's Income for Payment of :			
1	Coal Hauling Contractors, 32 km	USD	2.57	195,994.09
2	Road Maintenance Contractor, 32 km	USD	0.19	14,489.84
3	Loading Coal to Truck at ROM	USD	0.30	22,878.69
4	Haul Road Lease from other Party	USD	0.77	58,721.96
5	Underpass Lease from other Party	USD	0.30	22,878.69
	Total Company's Revenue (Gain), USD:			**314,963.27**

(*Source* : Author's Estimation base on Company's Data)

4. Implementation Plan

In order for this LS-WIM truck scale project to be implemented well, the following steps that proposed by the author:

Investment Proposal

Create and submit an Investment Proposal (CAPEX) for the construction of this LS-WIM truck scales, included with project information, objectives, business impact, pavement design, building design, electrical and plumbing design, planning drawings, owner estimates, term of reference, time frames, and team members, until this an Investment Proposal would be approved by company's management.

Procurement and Tender

After this investment proposal will be approved by management, the next step is procurement and tender process that conducted by corporate procurement team, to obtain credible contractors and reasonable quotation according to the market price to then create a work contract.

Construction

At this stage, the contractor must complete the safety aspects that apply to BIB first before the physical work of the project begins, such as medical check-up (MCU), safety induction, commissioning of mobile and non-mobile equipment, job safety analysis (JSA), permits to start project work, and appropriate personal protective equipment (PPE). This project should be finish in 16 weeks as shown in Figure 18.

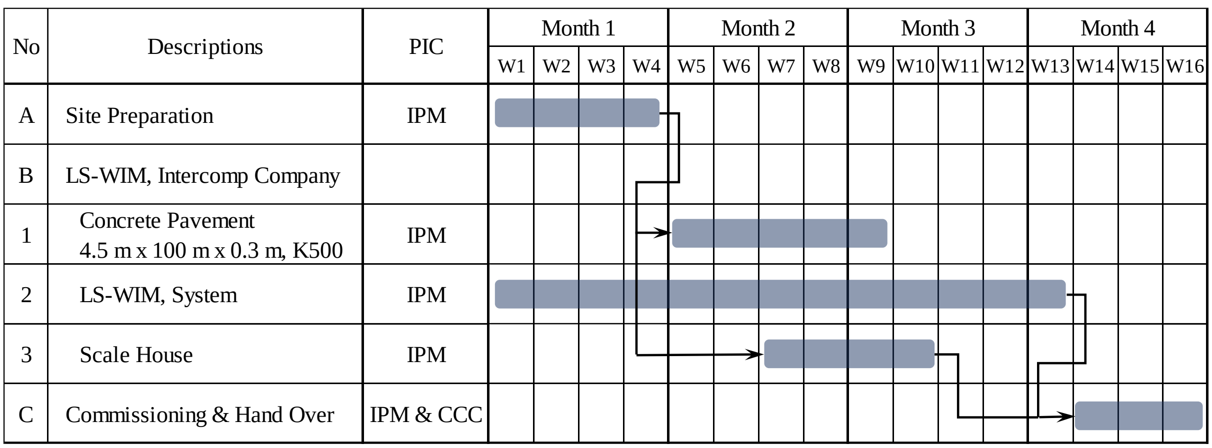

Figure 11. Gantt Chart of LS-WIM Implementation

Commissioning and Hand Over

Commissioning includes inspection by company's supervisor as a company representative together with the project contractor to ensure that the contractor has carried out the entire scope of work as stated in the work contract. Before the LS-WIM is tested by the Legal Metrology Standardization Center (BSML) of the Ministry of Trade of the Government of Indonesia to obtain a legal metrology certificate, internal calibration and dynamic internal testing are first carried out to ensure weighing accuracy in accordance with the agreed weighing accuracy specifications, which is a maximum of 2% per weighing transaction and 0.5% for the entire transaction. This work is declared complete when the LS-WIM has been handed over to the project user, Coal Chain Coordinator & Head of CPP Operations Department.

Table 20. Table Implementation Plan (Plan-Do-Check-Act (PDCA)

No	Implantation Plan	PIC	Outcome (Do)	Check	Act
1	Investment Proposal	IPM & CCC	Investment Proposal	Fail/Done	Revise Proposal
			Documents Approved	Fail/Done	Revise TOR

			Term of Reference (TOR)		
			Owner Estimate	Fail/Done	Revise TOR
			Purchase Requisition	Fail/Done	Revise PR
2	Procurement and Tender	IPM, CCC, Corporate Procurement	Bidder Qualification	Fail/Done	Looking for new bidders
			Project Tender	Fail/Done	Looking for new bidders
			Work Contract / Purchase Order	Fail/Done	Follow up to Procurement
3	Construction	IPM	Project Executed meet budget, quality, and schedule	Fail/Done	Result not accepted / rework
			Calibration	Fail/Done	Result not accepted / rework
			Trial Internal, cumulative accuracy below ± 0.5%	Fail/Done	Result not accepted / rework
4	Commissioning and Hand Over	IPM & CCC	Legal Metrology Certification	Fail/Done	Re-calibration
			Hand over	Fail/Done	Closing findings

Table 20 contains details of LS-WIM Implementation, complete with stages, responsible Person in Charge (PIC), and outcome that must be obtained, every effort to obtain outcomes is not always immediately successful, for that a check is needed, if it is not successful, action is needed to improve or other efforts so that the expected outcome can be successful.

5. Justification of Implementation Plan

There is a possibility that the weighing accuracy does not meet the target of 0.5%, the mitigation for this is by adding LS-WIM in the same pavement lane, so that the numbers of LS-WIM are two units and the weighing result is the average of the two LS-WIM which is automatically averaged in the weighing system. Ideally, the addition of this LS-WIM to obtain accuracy according to the work contract does not add cost, because it has been mutually agreed upon for the results of this accuracy.

CONCLUSION

This research identifies the continued use of manual weighing in coal mining operations and analyzes the root cause through interviews, focus group discussions (FGDs), and field observations using the Current Reality Tree (CRT) tool. Stakeholders highlighted three key criteria for weighing processes: accuracy, productivity, and investment cost. Based on these criteria, three alternatives—Weighbridge, LS-WIM, and HS-WIM—were evaluated using the Analytic Hierarchy Process (AHP), with LS-WIM emerging as the best solution. The research proposes a phased implementation of LS-WIM, including stages such as investment proposal, procurement, construction, and commissioning. Short-term and long-term recommendations are made to ensure LS-WIM's success, with considerations for truck dimensions and real-time data integration. Future research could examine the long-term effectiveness of LS-WIM, compare it to manual weighing, and explore the integration of emerging technologies or hybrid systems to improve scalability, operational efficiency, and collaboration among stakeholders.

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