Volume 4, No. 9 September 2026, pp. 1152-1167
e-ISSN 3031-5786
DOI: https://doi.org/10.46799/adv.v4i9.661

Improvement and Acceleration of Rebuild and Conversion Process for ore Wagon at Grasberg Block Cave Mine PT Freeport Indonesia

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Keywords:
Capacity Planning; Ore Wagon; Rebuild and Conversion Process; Wet Muck

Abstract

The transition to wet muck-dominated production at PT Freeport Indonesia's Grasberg Block Cave mine requires reliable conversion of dry-model ore wagons into wet-model units; however, delays in transportation and workshop activities have constrained production output. This study aimed to identify the root causes of inefficiencies across the Underground–Highland–Lowland logistics route and the rebuild station, as well as to formulate measures capable of sustaining a conversion rate of two wagons per week. A mixed-method approach was employed, combining field observations, project progress records, and a focus group discussion involving five stakeholder representatives. Fishbone analysis was used to examine logistics-related delays, while the Current Reality Tree was applied to identify workshop bottlenecks. Eleven alternatives were evaluated using Kepner–Tregoe Decision Analysis and Potential Problem Analysis. The findings revealed several constraints, including limited lowboy availability, access queues, coordination gaps, restricted workshop space, shared labor resources, wheelset queues, unsuitable tools, inaccurate rubber component dimensions, and paint damage risks. The use of Flat Rack Container transportation, exclusion of wheelsets from the main rebuild quotation, and separate quotations for decoupler fabrication emerged as priority short-term solutions. Five cumulative capacity improvement levers were projected to reduce the average cycle time from 23.84 to 14–15 days per wagon and increase sustainable output from approximately 2.5 to eight wagons per month. These measures provide a roadmap for meeting conversion demand before wet muck becomes the dominant production condition.

INTRODUCTION

PT Freeport Indonesia (PTFI) operates the Grasberg mineral district in Papua, Indonesia. PTFI transitioned from open-pit mining at the Grasberg mine to an underground mining system following the depletion of surface mining operations. The three currently active underground mining operations in the Grasberg Mining District are the Grasberg Block Cave (GBC), the Deep Mill Level Zone (DMLZ) block cave mine, and the Big Gossan open stoping operation. Currently, the GBC mine has become one of the key components of PTFI's transition toward fully underground mining (Lalang, 2024; Nguz Tshisens et al., 2022; Panjaitan et al., 2024; Rubio Esquivel & Fuentes Bustamante, 2026; Rumbewas & Adhiutama, 2019). The GBC mine is a panel caving operation with a planned peak production capacity of 155,000 tons per day (tpd) in 2026 and an estimated mine closure date in 2038.

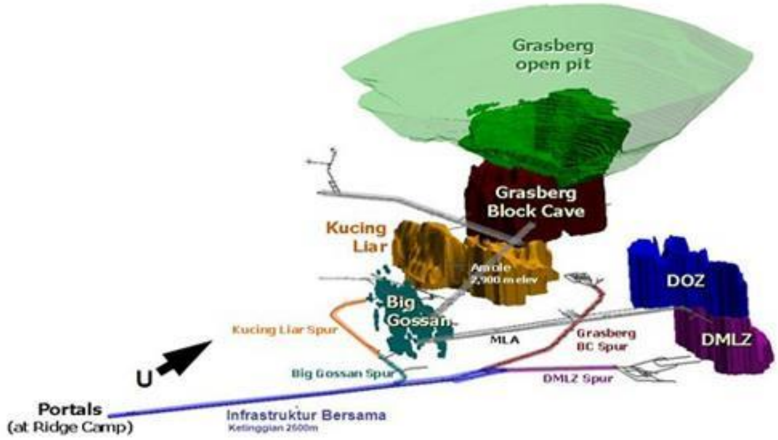

Figure 1. PTFI Underground Mining Area (Source: www.ptfi.co.id)

Ore transportation at the haulage level (2760L) uses a rail system. Each train consists of 11 bottom-dump Nordic Mine-Steel Technologies (NMT) ore wagons with a capacity of 20 m³, powered by an automated electric Schalke locomotive. PTFI operates 15 trains, with one designated as a spare, to maintain continuous production. Although block caving provides high production capacity, it also presents significant operational risks, particularly the occurrence of wet muck. Wet muck refers to sudden inflows of unsorted fine-grained particles and water discharged from draw points. A mixture of fine ore material and water, with water content exceeding 8.5%, has the potential to flow or slide suddenly under moist to wet conditions (Clarke & Jakubec, 2026; Niu et al., 2023; Walding, 2025; Walding et al., 2023).

Dry-model wagons, which were originally designed to handle fragmented ore under dry conditions, have limited capability in handling wet muck. This limitation may result in material spillage during dumping from the chute and while traveling along the track (Figure 2). To address these challenges, wagon conversion is required to improve resistance to wet muck conditions by adopting a wet-model design equipped with molded rubber liners and rubber spill lips (Figure 3). Table 1 presents the technical specifications of the NMT dry-model wagon currently operated at the GBC mine.

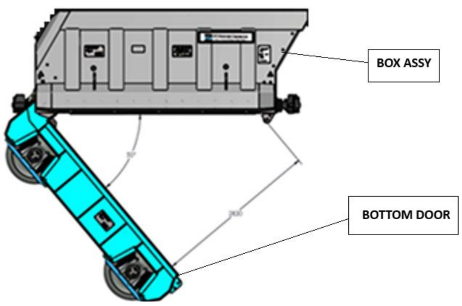

Figure 2. NMT Dry Model Wagon (Dry Model Wagon) (Source: PTFI Internal)

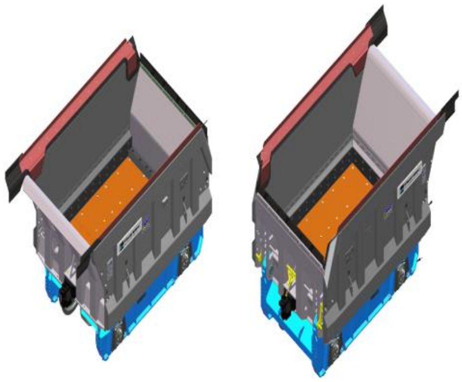

Figure 3. NMT Wet Model Wagon (Wet Model Wagon) (Source: PTFI Internal)

Table 1. NMT Wagon Technical Specification

Specification	Value	Specification	Value
Track Gauge	1.435 mm	Maximum Axle Load	35,000 kg
Max. Payload	38,000 kg	Designed Speed	20 km/h
Height	2,800 mm	Maximum Speed	25 km/h
Width	3,000 mm	Maximum Cars per Train	20
Length	4,597 mm	Minimum Curve Radius	60 m
Wheelbase	2,600 mm	Max Allowed Specific Gravity of Material	1,900 kg/m^3

(Source: PTFI Internal)

Meanwhile, for wagon maintenance strategy, PTFI already applies a Rebuild program to restore equipment to a "like-new" condition rather than replacing the unit. Between operating years, wagons are exposed to extreme conditions such as abrasive ore loads, high-frequency cycles, and continuous mechanical stress. Aligned with this rebuild program, the conversion from dry wagon to wet wagon is integrated into the rebuild process as PTFI's strategy to face the wet muck challenge on the GBC mine (Lara et al., 2020; Pollard & Buckley, 2025; Siregar, 2023).

Company Profile

PT Freeport Indonesia (PTFI) is a leading mining company operating in the mineral district of Grasberg, Central Papua, Indonesia, and is widely known as the manager of one of the largest copper and gold reserves in the world. PTFI is an affiliate of Freeport-McMoRan and MIND ID, with a shareholding composition of 51.23% of MIND ID and Freeport-McMoRan of 48.77% since the divestment agreement in December 2018. The business issues in this study are sourced from the Rolling Stock Maintenance Department, a business unit responsible for the maintenance of locomotives and carriages (Idris et al., 2022; Islam, 2015; Kans & Ingwald, 2023; Kumari et al., 2022; Mukwakungu et al., 2019). All of PTFI's operational activities are guided by the company's core values known as SINCERE, namely Safety, Integrity, Commitment, Respect, and Excellence, which is the reference for safety, responsibility, and continuous improvement standards in all mining activities.

Business Issue

Based on PTFI's forecast, wet muck production at GBC is predicted to dominate more than 70% of production by mid-2026, as shown in the wet muck prediction trend in Figure 4. At present, the haulage system operates a total of 170 ore wagons deployed at the haulage level. At the end of 2025, 25 wagons had successfully undergone rebuild and conversion, while 53 wagons remained pending, and the remaining 92 wagons were already wet-model units engineered directly by the manufacturer, NMT.

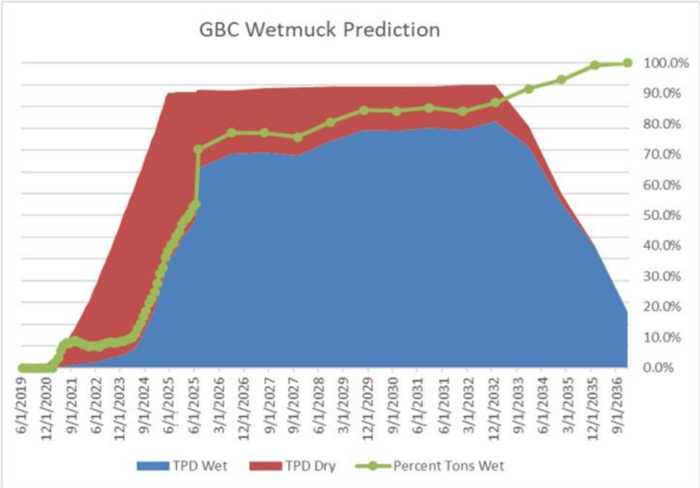

Figure 4. Prediction of Wet Muck Dominance in GBC Mines (GBC Wet Muck Prediction) (Source: PTFI Internal)

To achieve the daily target of 155,000 tons, a minimum number of wagons must always remain operational. Based on the average locomotive performance of 463 tons/hour (Table 2), the daily capacity per locomotive is 11,112 tons/day, so at least 14 locomotives (154 wagons) must operate simultaneously to meet the production target.

Table 2. Locomotive and Wagon Capacity Requirement for the 155,000 tpd Target (Locomotive & Wagon Capacity Requirement)

Parameters	Value
Average locomotive performance	463 tons/hour
Daily capacity per locomotive	11,112 tons/day
Locomotives required	13.94 → 14 units
Wagons per locomotive	11 wagons
Minimum wagons for 14 trains	154 cars
Total locomotive fleet	15 units
Required locomotive PA	93%
Total wagon fleet	170 units
Required wagon based on 93% PA	93% of 170 = 158 wagons
Operational spare for wagon	170 − 158 = 12 wagons

However, since the wagon rebuild and conversion program started in early 2025, the process has continued to experience delays and inconsistencies. Table 3 shows that the current wagon rebuild turnaround time (TAT) ranges from 23 to 32 days, with an average of 26 days, which is not yet consistent with the required cycle to keep pace with the wet muck transition.

Table 3. Turnaround Time (TAT) of the Rebuild Process of Existing Conditions

Unit No.	Transport to Tera	Transport to LL	Arrived at SSB	Finish Rebuild	TAT (days)
MW-0015	14-Jul-25	17-Jul-25	18-Jul-25	6-Aug-25	27
MW-0016	14-Jul-25	17-Jul-25	18-Jul-25	7-Aug-25	28
MW-0017	9-Aug-25	12-Aug-25	13-Aug-25	4-Sep-25	30
MW-0018	9-Aug-25	12-Aug-25	13-Aug-25	3-Sep-25	31
MW-0019	4-Sep-25	5-Sep-25	6-Sep-25	27-Sep-25	29
MW-0020	4-Sep-25	5-Sep-25	6-Sep-25	28-Sep-25	28
Average TAT					29

(Source: PTFI Internal)

Delays are found on both the logistics side (transport between Underground/UG, Highland/HL, and Lowland/LL facing inconsistency, priority queues, and poor communication among stakeholders) and the rebuild station side (no permanent bay assignment, forcing sequential rather than parallel activities). This situation raises two questions that this research aims to answer (Alam, 2021; Clark et al., 2018; Hajer & Versteeg, 2019; Iglesias-Pradas et al., 2021).

Research Questions and Objectives

The research questions in this study are: (1) What are the root causes of delays and inefficiencies in the current ore car rebuild process along the UG–HL–LL Rebuild Station workflow and back to HL–UG at PT Freeport Indonesia? (2) How can we increase and accelerate the output rate of the rebuild and conversion process of the wagon to deal with the dominance of wet muck? In line with this question, the objectives of this study are: (1) to identify and analyze the root causes of delays and inefficiencies in the ore wagon rebuild process along the UG–HL–LL Rebuild Station workflow; and (2) to increase the capacity of the Rebuild Station to produce consistent rebuild output and wagon conversion every week.

Research Scope and Limitations

This study is limited to the ore car rebuild workflow along the UG–HL–LL–Rebuild Station–LL–HL–UG, including transportation, inspection, disassembly, repair, reassembly, and return of the car to operational service. Data were analyzed using a Problem Analysis tool in the period January to May 2026 for logistics data, and January to September 2025 for rebuild process data at SSB stations. This study focuses on existing process improvements and does not include advanced automation, carriage redesign, or cost optimization. Wagon transportation data was conducted in January 2026 using two carriage samples, NMT#41 and NMT#42, to assess the transportation process and related operational activities.

METHOD

This study employed a mixed-method approach combining qualitative and quantitative methods to identify the root causes of delays in the ore wagon rebuild process. The data were categorized into two main streams: logistics flow data and rebuild process data at the station. These data were analyzed to identify bottlenecks in transportation, coordination, and technical aspects before formulating alternative solutions.

Data Collection Methods

Quantitative data was collected through field observations in the January 2026 period of NMT#41 and NMT#42 cars, including records of the target and realization of conversions, distribution of wet and dry cars in each locomotive, and variations in turnaround time of the rebuild process. The second data is sourced from the progress report on the rebuild and conversion of PT Sanggar Sarana Baja (SSB) as the manager of the Rebuild Station in Lowland, which was collected in the January-September 2025 period, including the planned and actual dates, duration, and percentage of completion of each stage of work.

Qualitative data was collected through a Focus Group Discussion (FGD) with five stakeholder representatives, namely: (1) Supervisor Mechanic from the Operation Maintenance Division; (2) Rolling Stock Maintenance Planner from the Operation Maintenance Division; (3) Supervisor from the Common Infrastructure Project Division (CIP); (4) Supervisor from PT Kuala Pelabuhan Indonesia (KPI) who is responsible for transporting cars from highland to lowland using lowboy trailers; and (5) Project Engineer from PT Sanggar Sarana Baja (SSB) who manages rebuild and conversion activities at the Rebuild Station.

Data Analysis Methods

This study uses three main analysis tools in order. First, the Fishbone/Ishikawa diagram is used to identify delays in terms of carriage delivery (logistics) based on the results of field observations. Second, the Current Reality Tree (CRT) is used to identify the root causes of delays in the process within the PT SSB Rebuild Station based on the project's Gantt Chart data, which is complemented by FGD results as supporting qualitative data. Third, Kepner-Tregoe (KT) Decision Analysis is used to evaluate and compare alternative solutions based on must-have and want-to-have criteria, followed by Potential Problem Analysis (PPA) as risk management for selected alternative solutions.

Table 5. Kepner-Tregoe Decision Analysis Template Used in Research

List of Alternatives	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Must-have (1)	Yes/No	Yes/No	Yes/No	Yes/No
Must-have (2)	Yes/No	Yes/No	Yes/No	Yes/No
Must-have (3)	Yes/No	Yes/No	Yes/No	Yes/No
Want-to-have (1–5), Weight (1–10)	Rating & Score (Weight×Rating)	Rating & Score (Weight×Rating)	Rating & Score (Weight×Rating)	Rating & Score (Weight×Rating)
Total Score	Alt. Score 1	Alt. Score 2	Alt. Score 3	Alt. Score 4

Source: (Based on Kepner & Tregoe, 1965)

After the weighting and assessment of the Kepner-Tregoe template has been obtained, the next stage is risk management through Potential Problem Analysis (PPA) as presented in Table 6, which highlights the potential risks associated with the selected alternative solutions.

Table 6. Potential Problem Analysis Risk Management Template

Alternative Solution	Risk Consequence	Probability of Occurrence (1–10)	Potential Impact (1–10)	Threat (Probability×Impact)
Alternative 1	Risk 1 / Risk 2 / Risk 3 / Total	–	–	–
Alternative 2	Risk 1 / Risk 2 / Risk 3 / Total	–	–	–
Alternative 3	Risk 1 / Risk 2 / Risk 3 / Total	–	–	–
Alternative 4	Risk 1 / Risk 2 / Risk 3 / Total	–	–	Sum of Threat

Source: (Based on Kepner & Tregoe, 1965)

The results of the Kepner-Tregoe Decision Analysis and Potential Problem Analysis are then synthesized into a number of recommendations, which are then poured into short-term and long-term implementation plans to optimize and accelerate the process of rebuild and conversion of the car.

RESULTS AND DISCUSSION

This chapter presents the results of data collection and analysis regarding the flow of the ore car rebuild and conversion process, starting from the Underground level where the car operates to the Rebuild Station in Lowland, Timika. Logistics data from field observations were analyzed using Fishbone Ishikawa, while Gantt Chart data provided by PT SSB was analyzed using Current Reality Tree. The resulting solution was then evaluated using Kepner-Tregoe Decision Analysis and Potential Problem Analysis.

Analysis of Carriage Transport between Highland and Lowland

The rebuild was carried out in the Lowland, while the carriages were operated by production locomotives at the Underground level in the Highland area. The two areas are separated by the Freeport main road (Milepost 66–32) with a distance of about three hours. Freeport applies strict convoy rules for buses and logistics trucks passing through the road, including escort by the Brimob, adherence to fixed departure schedules, and prohibition of leaving convoy formations. Based on observations and historical data, the carriage transportation process between HL and LL was analyzed using Fishbone Ishikawa diagrams to identify the causes of delays in method, machinery, human, measurement, and environmental aspects.

The results of Fishbone's analysis show that the inconsistency of the turnaround time of carriage transportation is not caused by a single bottleneck, but by a number of weaknesses in the aspects of method and coordination. The most basic root causes identified are: (1) fully assembled carriages can only be transported by lowboy trucks, while the availability of lowboys is very limited (only 7 units for the entire HL–LL–HL transportation cycle); (2) forklift access queues when crossing Portal AB also create delays in the transportation chain; and (3) multiple handoff gaps between responsible stakeholders (CIP, KPI, and Operations Maintenance) which increase the waiting time each time the carriages are in the staging area, as well as causing the absence of a fixed transportation schedule because each trip is planned reactively.

Station Rebuild Process and Gap Analysis

The Rebuild Station managed by PT Sanggar Sarana Baja (SSB) is located at the Lowland Freeport facility. Based on existing conditions, PT SSB's performance has not met PTFI's target of eight cars per month. The process includes disassembly, repair, welding, wet kit installation, sandblasting, painting, and final assembly to restore the carriage's function while converting it to a wet muck version. Analysis of the gap between the plan and the realization of eight carriage units (NMT-018 to NMT-025) shows that the largest gap occurs in the Wheelset, Fabrication Decoupler Assy, and Box Assy stages, as summarized in Table 7.

Table 7. Average Gap between Plan and Actual per Process Stage

Phase	Average Plan (days)	Actual Average (days)	Average Gap (days)
Box Assy	11,9	17,0	5,1
Bottom Door	7,8	11,0	3,2
Wheelset	2,0	9,7	7,7
Fab Decoupler Assy	1,5	9,0	7,5
Re-Assembly All Component	2,7	4,1	1,4

The Current Reality Tree analysis conducted with the Focus Group Discussion on the Gantt Chart of the PT SSB project identified eight root causes that underlie the three undesirable effects above, namely: (1) the current wheelset has to wait for another wheelset of the production spare to be reprofiled due to priority; (2) there is only one sandblast and painting room available for the entire work at the SSB Workshop; (3) one bay can only accommodate one set of carriages (Box Assy and Bottom Door); (4) only one stand is available for the Bottom Door; (5) the assigned labor is the same as the labor at the reassembly point; (6) the accuracy of the rubber dimensions is not precise to install; (7) the drill bit chosen is not compatible with the hard steel on the Box Assy wall; and (8) there is no new paint surface protection from contact with the lifting gear.

Development of Alternative Solutions

By combining the root causes of the two analysis streams (carriage logistics and Rebuild Station), as well as considering safety, operational, and technical aspects, this study formulates alternative solutions through a Forum Group Discussion with stakeholders. For the logistics side, the resulting alternatives include the appointment of a clear Person in Charge (PIC) for CIP, KPI, and Operations Maintenance; the establishment of a standard transportation schedule with fixed departure and arrival times; and the implementation of Flat Rack Container for carriage transportation on the HL-LL-HL-UG route, which does not require an access permit through the AB Portal as in the lowboy truck method. For the Rebuild Station side, the resulting alternatives include the exclusion of the wheelset from the main rebuild quote and its combination with other wheelset quotes; the procurement of laser cleaning machines for parallel sandblasting; the designation of Bay 6 (formerly the repair bay) as the second reassembly area; additional fabrication of stands to accommodate two sets of Box Assy and Bottom Door; submission of separate quotes for decoupler fabrication; inspection and provision of rubber dimension templates; use of special hard steel tungsten carbide drill bits; as well as installation of temporary guards on lifting equipment to prevent paint damage.

Kepner-Tregoe Decision Analysis and Potential Problem Analysis

The eleven alternative solutions were then evaluated using the Kepner-Tregoe Decision Analysis based on must-have criteria (TAT reduction, short-term implementation, and cost avoidance of rework) as well as want-to-have criteria (ease of implementation, operational impact, resource requirements, labor intensity, and integration with existing processes). The ranking results are presented in Table 8.

Table 8. Rank 11 Alternative Solutions based on Kepner-Tregoe Decision Analysis Score

Ratings	Alternative Solutions	Total Score
1	Designating Bay 6 as the second reassembly area	284
2	Implementation of Flat Rack Container for HL-LL-HL-UG transportation	283
3	Exclude wheelsets from the main rebuild quote	276
4	New quotes to exclude decoupler fabrication	234
5	Use of special drill bits for hard steel	233
6	Clear designation of PICs for CIP, KPIs, and Operations Maintenance	223
7	Procurement of laser cleaning machine for parallel sandblasting	216
8	Fabrication of additional stands for 2 Box Assy and 2 Bottom Door	209
9	Temporary protective attachment during lifting	208
10	Determination of standard transportation schedule	204
11	Rubber inspection and preparation of dimensional templates	181

Designating Bay 6 as the second reassembly area earned the highest score (284) due to its very strong operational impact and its integration with existing workshop layouts without the need for new civil work. The Flat Rack Container implementation ranked second (283) because it directly addressed the two root problems at once, namely lowboy bottlenecks and AB access restrictions, with a high labor intensity and integration score. The wheelset exclusion from the main quote ranked third (276) with the highest ease of implementation score due to its administrative/planning nature.

Furthermore, eleven alternatives were evaluated through Potential Problem Analysis to identify the implementation risk (Risk Consequence) along with its probability and impact, so that a Total Threat score was obtained as presented in Table 9.

Table 9. Total Threat Rating of Potential Problem Analysis (lower the better)

Ratings	Alternative Solutions	Total Threat
1	Implementation of Flat Rack Container for HL-LL-HL-UG transportation	92
2	Exclude wheelsets from the main rebuild quote	97
3	New quotes to exclude decoupler fabrication	98
4	Clear designation of PICs for CIP, KPIs, and Operations Maintenance	102
5	Fabrication of additional stands for 2 Box Assy and 2 Bottom Door	104
6	Temporary protective attachment during lifting	105
7	Use of special drill bits for hard steel	107
8	Determination of standard transportation schedule	111
9	Designating Bay 6 as the second reassembly area	116
10	Procurement of laser cleaning machine for parallel sandblasting	130
11	Rubber inspection and preparation of dimensional templates	146

By comparing Table 8 and Table 9, three short-term solution recommendations were obtained with the highest criteria score as well as the lowest threat score, namely: (1) implementation of Flat Rack Containers for HL-LL-HL-UG transportation; (2) wheelset exclusion from major rebuild quotes; and (3) new quotes to exclude decoupler fabrication. These three solutions are equipped with contingency plans, including the provision of eight PTFI Flat Rack Container units (four in Highland and four in Lowland) along with competent rigging mechanics to address the complexity of container fittings, the provision of wheelset buffer stock to anticipate supply disruptions, and the preparation of an early draft agreement to expedite the new quote approval process.

Rebuild Station Capacity Planning (Long-Term Implementation)

In addition to the three short-term priority solutions, eight other alternative solutions from the Current Reality Tree analysis are mapped into five capacity planning levers to achieve a sustainable output target of eight cars per month or two cars per week. Based on historical data of eight car units (NMT-018 to NMT-025), the current average actual turnaround time is 23.84 calendar days per car, compared to the baseline plan average of 18.90 days. Table 10 summarizes the projected cycle time after each lever is applied cumulatively.

Table 10. Projection of Cumulative Cycle Time After Application of Each Capacity Lever

Cumulative Lever	Day/Carriage	Output/Month	Remarks
Current process (baseline)	23.84 days	≈ 2.5	No corrective action
+ Lever 1: Wheelset Exclusion	20.89 days	≈ 2.9	Duration lever
+ Lever 2: Decoupler Fabrication Exclusion	18.02 days	≈ 3.3	Duration lever
+ Lever 3: Laser cleaning/parallel sandblasting	16.07 days	≈ 3.7	Duration lever
+ Lever 4: Bay 6 as the second rebuild path	16 days	≈ 7.5	Capacity lever (parallel)
+ Lever 5: Rubber hole template, drill bit, protector	15 days	≈ 8.0	Quality protection lever
Sustainable output targets	≤ 15 days	8	PTFI's Needs

Levers 1 to 3 are the duration levers that eliminate the three largest sources of waiting time (idle/queue) so that the duration per car is reduced from 23.84 to about 16.1 days. Lever 4 is a capacity lever that does not reduce the number of days per car, but doubles the number of cars that can be processed simultaneously to 7.5 cars/month through two parallel reassembly lines. Lever 5 is a quality protection lever that prevents rework (re-drilling, repainting, and reinstallation) so that the output of eight cars/month or two cars/week can be maintained sustainably in a cycle of 14–15 days per car.

With the combination of these three short-term priority solutions and five long-term capacity levers, Rebuild Station is projected to be able to achieve the output target of two cars per week consistently in the second month of implementation, in line with the need for stable carriage delivery to Rebuild Station every week, so that PT SSB and PT Freeport Indonesia can meet the needs of wagon conversion ahead of wet muck dominance.

Implementation Plan and Output Projection

The short-term implementation plan is prepared based on three alternative solutions with the highest Kepner-Tregoe score and the lowest Potential Problem Analysis score, as summarized in Table 11. Each solution is equipped with a Person in Charge (PIC) and key activities to immediately have an impact on reducing turnaround time.

Table 11. Short-term Implementation Plan for 3 Priority Solutions

Solution	Main Activities	Person in Charge (PIC)
Flat Rack Container	Procurement of 8 units of PTFI's Flat Rack Containers (4 in Highland, 4 in Lowland); preparation of fitting SOPs and appointment of rigging mechanics	Planner & Operations Maintenance
Wheelset Exclusion	Separation of wheelset quotes from main rebuild quotes; alignment of schedules with PT SSB's wheel reprofiling stations	Rolling Stock Maintenance Planner
Decoupler Fabrication Exclusion	Submission of new quotes for decoupler fabrication outside the scope of the main project; separate labor allocation	PT Sanggar Sarana Baja (SSB)

Furthermore, the combination of the short-term plan and five levers of long-term capacity is projected to result in a gradual increase in the output of the Rebuild Station from two cars per week that was not consistent in the first month to a consistent two cars per week in the second month, as presented in Table 12.

Table 12. Projected Output of Rebuild and Conversion with a Target of 2 Cars per Week (Forecast Output)

Period	Input Carriage to Rebuild Station	Carriage Output from Rebuild Station	Remarks
Month 1 – Weeks 1–4	2 carriages/week (gradual)	Not consistent (ramp-up)	Application of Lever 1–3 (duration lever)
Month 2 – Weeks 1–2	2 carriages/week	Close to 2 cars/week	Application of Lever 4 (Bay 6 parallel)
Month 2 – Week 3–4	2 carriages/week	Consistent 2 carriages/week	Application of Lever 5 (quality protection)

Table 12 shows that in the second month, the output level of the Rebuild Station is projected to reach PTFI's requirement of two cars per week, provided that the delivery of cars to the Rebuild Station is also consistent with two cars per week. This consistency between inputs and outputs is key to the success of the rebuild and conversion acceleration program ahead of the full dominance of wet muck in GBC production.

CONCLUSION

This research focused on the ore wagon rebuild and conversion project at PT Freeport Indonesia, including the wet-model conversion required to address the wet muck challenge at the Grasberg Block Cave mine. The root causes of delays were identified across two process streams: wagon logistics between Highland and Lowland and the rebuild process at the PT Sanggar Sarana Baja workshop. The analysis was conducted using Fishbone Ishikawa analysis and Current Reality Tree analysis, which identified eight underlying root causes.

Through Kepner–Tregoe Decision Analysis and Potential Problem Analysis, three alternatives achieved the highest evaluation scores with the lowest risk levels and were recommended as short-term solutions: implementing Flat Rack Container transportation for HL–LL–HL–UG routes, excluding the wheelset from the main rebuild quotation, and issuing a separate quotation for decoupler fabrication. To increase rebuild station capacity and maintain consistent weekly output, the remaining eight alternatives were mapped into five capacity levers, consisting of duration improvement levers, a capacity enhancement lever, and a quality protection lever. These measures were projected to reduce the average cycle time from 23.84 to 14–15 days per wagon and increase sustainable output to eight wagons per month, meeting PTFI's requirements before wet muck becomes dominant in production.

It is recommended that PT Sanggar Sarana Baja and PTFI's Operations and Maintenance Division conduct periodic reassessments using the same root-cause analysis framework, as new undesirable effects may emerge after resolving the wheelset, decoupler, and sandblasting bottlenecks. In addition, the wheel-reprofiling exchange process should be formalized into a written standard operating procedure (SOP) with buffer stock provisions and clear escalation triggers to prevent it from becoming a future bottleneck. Since container-tagging technology is already in use, future research could integrate real-time Internet of Things (IoT) or radio-frequency identification (RFID) tracking into the Current Reality Tree and Kepner–Tregoe frameworks to enable more dynamic and continuously updated analysis. This approach would provide both parties with a structured roadmap for sustaining the rebuild and conversion program beyond the scope of this study.

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