

Replacement Plan Analysis for Light Vehicle at PT Freeport Indonesia Using Multi-Criteria Decision Making (MCDM)

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Abstract

This study was motivated by the increasing complexity of fleet management in mining operations, particularly due to aging vehicles, rising maintenance costs, and the growing demand for high operational reliability. Light vehicles play an essential role in supporting daily mining activities, including personnel transportation and logistics distribution; therefore, inappropriate replacement decisions may reduce operational efficiency and increase operational risks. To address this challenge, this study incorporated a comprehensive set of evaluation criteria covering economic, technical, and operational aspects. Economic criteria included initial acquisition cost, operating expenses, maintenance costs, and residual value, while technical criteria covered vehicle reliability, fuel efficiency, and mechanical failure frequency. Operational considerations, including vehicle availability, utilization rate, safety standard compliance, and environmental impact, were also incorporated to provide a comprehensive assessment. The data used in this research were obtained from company databases, maintenance records, and expert evaluations from experienced practitioners. By applying Multi-Criteria Decision Making (MCDM) techniques, this study systematically analyzed and ranked alternative replacement options to identify optimal replacement timing and priorities. The application of the MCDM approach enhanced the quality and objectivity of vehicle replacement decisions at PT Freeport Indonesia. The results indicated that some older vehicle units remained economically and operationally feasible due to stable performance and relatively low operating costs. The proposed model has the potential to reduce total lifecycle costs, improve fleet availability, and enhance overall operational productivity.



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INTRODUCTION

Mobile equipment, including light vehicles, plays a vital role in supporting mining operations, where equipment availability, reliability, and safety directly influence productivity and operational performance. Light vehicles are widely used to support transportation, maintenance, supervision, and other operational activities across mining sites. As vehicle fleets age, maintenance costs increase, reliability declines due to component obsolescence and outdated technology, and the risk of operational disruption becomes more significant (Janson & Norman, 2020; Karaani et al., 2025; Klisura et al., 2025; Ntanis et al., 2024).

Many mining companies continue to rely on traditional replacement approaches based primarily on vehicle age or accumulated mileage (Al-Chalabi, 2022). Although these indicators are useful, they often fail to capture the multiple factors influencing replacement decisions, including maintenance expenditure, utilization rate, operational availability, safety

performance, and residual value (Castañón et al., 2024; Samatumba et al., 2020). PT Freeport Indonesia (PTFI), one of Indonesia's largest copper and gold mining companies, operates one of the world's largest integrated mining complexes in Papua and manages a substantial fleet of approximately 2,200 internal combustion engine (ICE) light vehicles, including pickup trucks, station wagons, and troop carrier vehicles, distributed across 27 operational divisions. These vehicles support workforce mobility, supervision, field inspections, maintenance activities, logistics coordination, and Shift Day Off (SDO) activities. Replacement decisions at this scale require a balance between financial considerations and operational as well as strategic objectives; therefore, a structured decision-making framework is required (Aiello et al., 2024; Gutiérrez-Díez et al., 2024).

A preliminary assessment indicated that PTFI's current replacement process was largely fragmented. Decisions relied on individual indicators, such as vehicle age, mileage, maintenance cost thresholds, and regulatory compliance requirements, supported by general condition reports prepared by maintenance personnel through visual inspections of vehicle body, engine, chassis, and interior conditions. However, these assessments did not integrate Total Cost of Ownership (TCO), safety risks, utilization performance, or emission targets. This practice resulted in (a) excessive maintenance and operating costs due to delayed replacement, (b) capital inefficiency due to premature replacement, (c) variability in service levels and downtime, and (d) missed sustainability and safety compliance targets. Table 1 summarizes the identified gaps in current practices across four dimensions: replacement criteria (What), replacement timing (When), organizational coverage (Where), and replacement magnitude (To What Extent), along with the corresponding expected improvements.

Table 1. Gap Analysis of Current Vehicle Replacement Practices and Expected Improvement

Dimension	Current Practice	Identified Gap	Expected Improvement
What	Replacement decisions are primarily based on vehicle age, mileage, maintenance-cost thresholds, and safety-compliance requirements.	Decisions rely on individual indicators and do not evaluate multiple criteria simultaneously; financial, operational, technical, and safety factors are not integrated into a unified decision framework.	Develop a Multi-Criteria Decision-Making (MCDM) framework that incorporates Total Cost of Ownership (TCO), operational performance, reliability, utilization, maintenance trends, and safety indicators.
When	Replacement decisions are made on an immediate basis due to breakdowns or compliance issues (short-term, under one year) or through long-term programs of three to five years.	Replacement timing is often reactive rather than proactive; future lifecycle-cost implications are not systematically considered.	Establish optimal replacement intervals based on lifecycle-cost analysis and predictive replacement planning.
Where	Replacement decisions are managed independently across approximately 27 operational divisions within PT Freeport Indonesia.	Variation in replacement practices results in inconsistent decision criteria and prioritization across divisions.	Implement a standardized replacement methodology applicable across all fleet-owning divisions.

Dimension	Current Practice	Identified Gap	Expected Improvement
To What Extent	Replacement planning is generally measured by number of vehicles replaced, percentage of fleet renewal, and annual capital-expenditure allocation (approximately USD 19 million).	Capital-allocation decisions are not explicitly linked to objective replacement priorities and asset lifecycle optimization.	Improve capital-investment effectiveness by prioritizing replacement candidates based on quantitative and qualitative performance criteria.

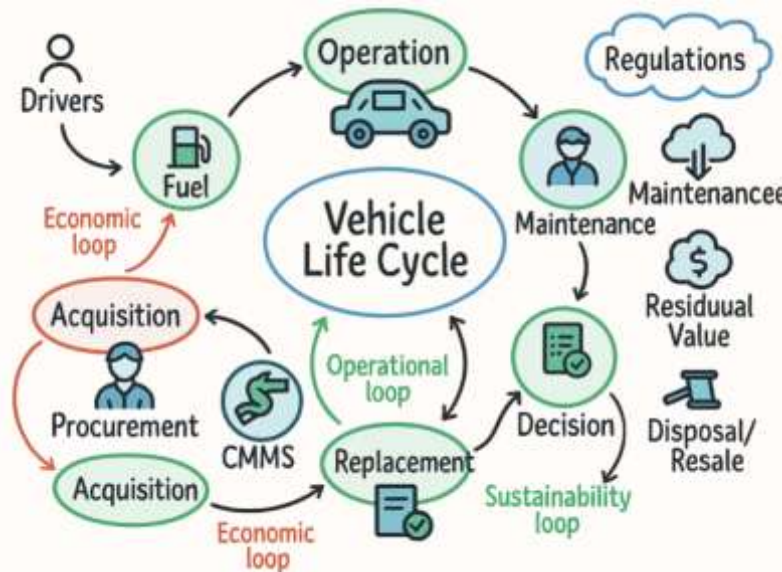


Figure 1. Light vehicle life cycle under current practice



Figure 2. Light vehicle replacement strategy before and after the structured replacement program

Light vehicles represent critical operational assets at PTFI. Work-tool vehicles, in particular, serve as essential operational resources for field supervisors, technicians, and maintenance crews rather than merely transportation facilities. Therefore, their unavailability

may delay activities across multiple departments (Chaowasakoo et al., 2018). Despite regular maintenance, components such as engines, transmissions, braking systems, and suspension assemblies gradually deteriorate through prolonged use (Odeyar et al., 2022). As vehicles approach the end of their economic life, maintenance requirements and failure probability tend to increase, resulting in higher maintenance costs, more frequent breakdowns, reduced availability, and increased downtime (Angeles & Kumral, 2020). In mining environments, these consequences extend beyond the vehicles themselves, potentially affecting supervision, maintenance execution, safety inspections, logistics activities, and production support, while also increasing personnel safety risks (Balaraju et al., 2019). A structured replacement program can reduce unplanned failures, improve availability, support lifecycle cost optimization, and assist management in prioritizing capital expenditures based on vehicle condition, operational importance, financial impact, and safety requirements (de Jonge & Scarf, 2020). Such a program is estimated to reduce capital expenditures by 5%–15% compared with the current plan while improving safety and operational efficiency.

This study was supported by three complementary theoretical perspectives. Fleet Optimization Theory emphasizes the efficient utilization of vehicle assets while minimizing operating costs, maintenance expenditures, and downtime. It also highlights how operator behaviors, including aggressive acceleration, harsh braking, excessive idling, and overloading, can accelerate component deterioration. Reliability-Centered Maintenance (RCM) provides a structured approach to maintaining assets according to their required functions and failure modes by linking maintenance history and reliability trends with replacement timing. Life Cycle Costing (LCC) and Total Cost of Ownership (TCO) provide the financial basis for evaluating the economic consequences of assets throughout their service life, including acquisition costs, fuel consumption, maintenance, spare parts, downtime, and residual value, rather than considering only the initial purchase price. Together, these perspectives support a transition from reactive, age-based replacement practices toward a structured and proactive process that considers not only vehicle age but also operational performance, operating and maintenance costs, reliability, and risks associated with continued use.

Based on this background, this study proposed the application of Multi-Criteria Decision Making (MCDM) techniques through the integration of the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). AHP was used to determine the relative importance of evaluation criteria through expert pairwise comparisons, while TOPSIS was applied to rank vehicle alternatives based on their relative closeness to an ideal solution. The objective of this research was to develop a decision-support model capable of identifying light-vehicle replacement priorities at PT Freeport Indonesia while simultaneously considering financial, operational, technical, and safety dimensions. This model was intended to support proactive and data-driven replacement decisions that reduce total lifecycle costs, improve fleet availability, and enhance operational productivity (Labib et al., 2026; Marevac et al., 2025; Mustafa, 2025; Potdar & Parikh, 2025; Wang, 2026).

The scope of this research was limited to light vehicles, including passenger vehicles, pickup trucks, sport utility vehicles, and troop carriers operating with internal combustion engine (ICE) technology within PTFI. These vehicles were evaluated using criteria derived from asset management, fleet optimization, RCM, and LCC/TCO principles. The study did not cover heavy mobile equipment, mining trucks, buses, or alternative propulsion technologies such as battery-electric or hybrid-electric vehicles. The analysis relied on historical fleet, maintenance, and financial data available during the study period. Safety assessment was based on fleet management indicators rather than detailed engineering analysis or crash-performance testing. Despite these limitations, this study provides a practical and systematic framework to support light-vehicle replacement planning, improve capital expenditure allocation, and

enhance operational reliability at PTFI. The findings may also be adapted to similar asset-intensive mining operations.

METHOD

Research Design

This study employed a quantitative decision-support approach to develop a fleet vehicle replacement strategy by integrating economic, operational, maintenance, and technical performance indicators to evaluate replacement priorities within PT Freeport Indonesia's light-vehicle fleet. A Multi-Criteria Decision Making (MCDM) framework combining the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was applied to address the complexity of replacement decisions. AHP was used to determine the relative importance of evaluation criteria through pairwise comparisons, while TOPSIS was used to rank fleet vehicles based on their relative closeness to the ideal replacement condition.

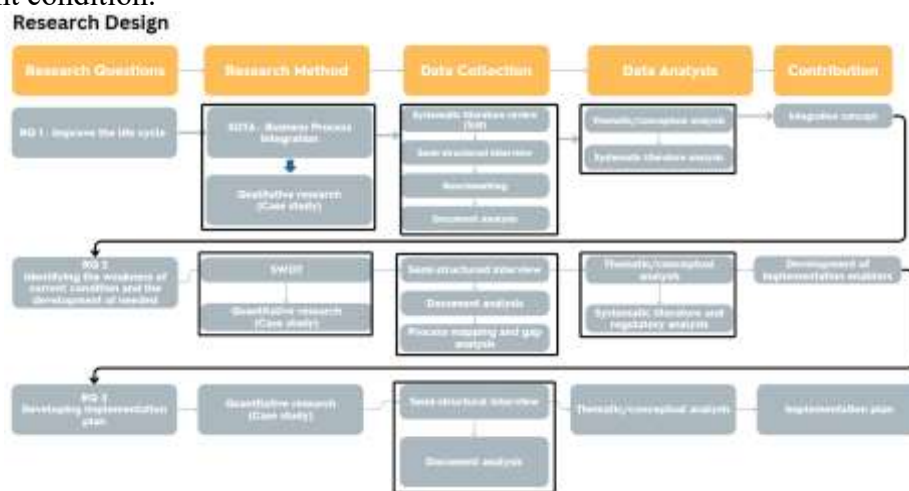


Figure 1. Research design flow

Research Framework and Location

The research framework consists of eight sequential stages: (a) identification of the fleet-replacement problem; (b) literature review and theoretical foundation; (c) determination of evaluation criteria and alternatives; (d) collection of fleet operational and maintenance data; (e) weight calculation using AHP; (f) vehicle ranking using TOPSIS; (g) analysis of results and replacement recommendations; and (h) development of the replacement strategy. This framework ensures that replacement decisions are systematic, transparent, and supported by quantitative analysis. The study was conducted within the Fleet Management department of PT Freeport Indonesia, focusing on operational vehicles currently used across the company's business activities.

Population and Sample

The population comprises all fleet vehicles operated by PT Freeport Indonesia during the study period, representing the assets considered for replacement evaluation—approximately 2,200 ICE light vehicles consisting primarily of pickup trucks, station wagons, and troop carrier vehicles. A purposive sample of 10 vehicles, drawn from several operational divisions, was selected because only vehicles with complete and reliable information can be evaluated using AHP-TOPSIS. Vehicles were included if they had been in operation for at least four years, had complete historical maintenance records, had available operational utilization data (odometer readings and annual mileage), had available records of maintenance cost, fuel consumption, downtime and reliability performance, were currently operating under normal mining conditions, and had not undergone major refurbishment or life-extension programs that could

alter their normal lifecycle characteristics. Vehicles were excluded if they were newly acquired with insufficient operational history, had incomplete records, had been permanently decommissioned before the study period, or were specialized vehicles not representative of the general light-vehicle fleet. Each of the 10 vehicle alternatives is evaluated using the criteria established in Table 2, and the resulting data are organized into a decision matrix that serves as the primary input for the AHP-TOPSIS analysis.

Research Variables

The evaluation criteria used in this study follow the twelve indicators presented in Table 2, grouped into four categories-financial, operational, technical, and safety-and classified as either cost criteria (lower values preferred: maintenance cost, vehicle age, downtime, odometer reading, breakdown frequency, accident history, critical safety defects) or benefit criteria (higher values preferred: residual value, vehicle utilization, fleet availability, mechanical condition, safety inspection score). This benefit/cost classification determines how the positive and negative ideal solutions are identified in the TOPSIS procedure.

Data Collection Methods

Primary data are obtained through interviews with fleet managers and maintenance supervisors, expert judgment for AHP pairwise comparisons, and discussions with vehicle operators. Table 5 presents the proposed interview respondents representing the key functional areas involved in fleet-replacement decision-making.

Table 2. Proposed Interview Respondents

No.	Respondent Position / Function	Recommended Number	Main Contribution
1	Fleet Manager / Fleet Superintendent	1	Fleet strategy, utilization, replacement policy
2	Fleet Engineer	1	Vehicle technical condition and lifecycle
3	Maintenance Superintendent	1	Maintenance strategy, repair costs, reliability
4	Maintenance Engineer	1	Failure history, maintenance frequency, technical performance
5	Asset Management Representative	1	Asset lifecycle, replacement planning, TCO
6	Finance / Capital Planning Representative	1	CAPEX, budget allocation, financial evaluation
7	Operations Representative	1	Operational requirements, availability, productivity
8	Safety Representative	1	Safety compliance, vehicle risk, incident considerations
Total		8	

Secondary data are obtained from fleet management records, vehicle maintenance history, fuel consumption reports, financial reports, asset registers, and vehicle utilization reports, providing the quantitative measurements required for the TOPSIS calculation.

Data Analysis Procedure

The data analysis proceeds through the following steps: (1) collecting operational and maintenance data; (2) identifying fleet vehicles as decision alternatives; (3) determining evaluation criteria; (4) obtaining expert judgments; (5) calculating AHP criterion weights; (6) verifying the consistency ratio; (7) developing the TOPSIS decision matrix; (8) performing the TOPSIS calculation; (9) ranking fleet vehicles; (10) identifying replacement priorities; and (11) formulating replacement recommendations. Figure 5 illustrates the AHP hierarchical structure used to translate this procedure into a decision model.

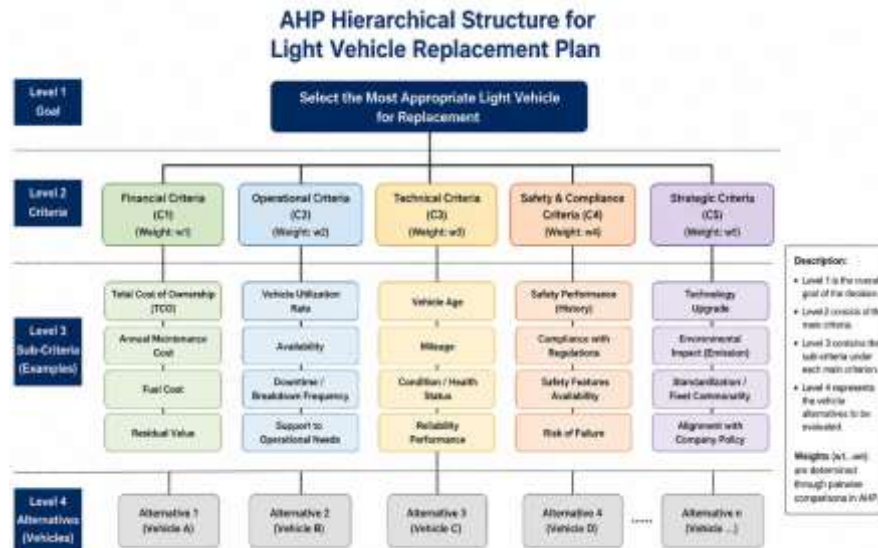


Figure 2. AHP hierarchical structure for the light vehicle replacement plan

Research Validation

Validation of the proposed decision model consists of four complementary stages. Technical validation compares the TOPSIS ranking results with historical fleet performance data-vehicle age, odometer reading, annual maintenance cost, availability, reliability records, downtime, breakdown history, fuel consumption, safety inspection records, and residual value-to determine whether vehicles ranked as high replacement priority also exhibit poor operational performance and rising lifecycle cost. Expert validation involves Subject Matter Experts from fleet, maintenance, asset management, finance, and operations functions, who review the selected criteria, the AHP hierarchy, pairwise comparison judgments, criteria weights, TOPSIS ranking outcomes, and final recommendations. AHP consistency validation applies the Consistency Ratio (CR) described in Section 2.5, with $CR < 0.10$ indicating acceptable consistency of expert judgment; otherwise the pairwise comparison matrix is reviewed and revised. Sensitivity analysis evaluates the robustness of the ranking by systematically adjusting AHP criteria weights-for example, increasing the weight of the operational, financial, safety, or technical category by 10%, or applying equal weighting across all main criteria as a benchmark-and repeating the TOPSIS procedure for each scenario. The proposed framework is considered valid when the AHP Consistency Ratio is below 0.10, the TOPSIS ranking is consistent with actual vehicle condition, fleet-management experts agree that the resulting priorities are practical, and the sensitivity analysis demonstrates that the ranking remains relatively stable under reasonable variation in criteria weights.

Research Flowchart

The overall methodology can be summarized as a sequential flow of problem identification, literature review, criteria determination, data collection, AHP weight calculation, consistency testing, TOPSIS analysis, vehicle ranking, replacement-priority determination, and strategy recommendation, as illustrated in Figure 6.

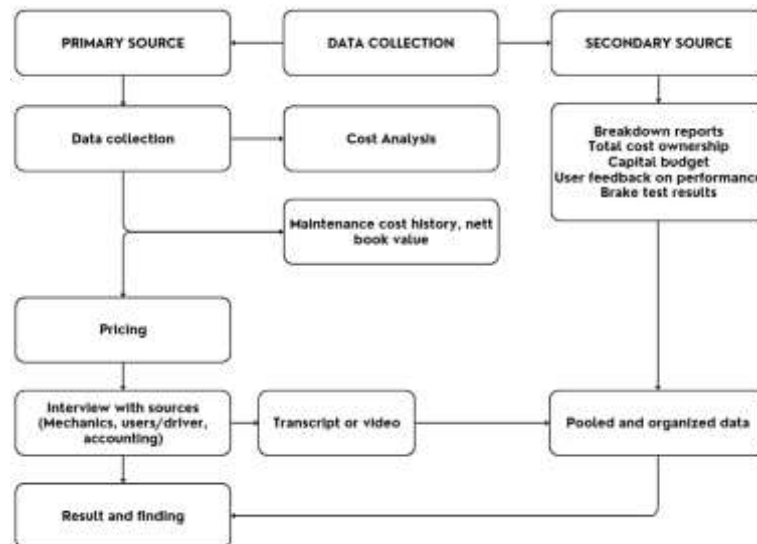


Figure 3. Research flow chart

RESULTS AND DISCUSSION

Company Profile and Existing Replacement Practices

PT Freeport Indonesia's operational activities are characterized by large geographical coverage, challenging terrain, high safety standards, continuous operational requirements, and significant dependence on fleet mobility, which make vehicle availability and reliability critical to business continuity. The fleet-management function is responsible for vehicle acquisition, fleet operation, preventive and corrective maintenance, asset-utilization monitoring, and replacement planning as part of the broader asset-management strategy. Based on interviews and document review, current replacement decisions are influenced mainly by vehicle age, mileage, maintenance history, operational requirements, and budget availability; although informative, this process remains dependent on managerial judgment rather than a formal multi-criteria evaluation framework, resulting in increasing maintenance cost, declining reliability, higher downtime frequency, limited replacement budgets, and difficulty prioritizing replacement candidates.

Data Description

This study evaluates a purposive sample of 10 light vehicles drawn from PTFI's operational fleet of approximately 2,200 ICE light vehicles, representing a range of operational conditions, service ages, utilization levels, and maintenance histories. Since PTFI has officially operated the Toyota Land Cruiser 70 Series (LC78 and LC79) since 2012 and added 145 new units in 2022, comparable vehicle models performing similar operational functions in mining environments are used as realistic replacement alternatives, as summarized in Table 3.

Table 3. Alternative Light Vehicles for PT Freeport Indonesia

Alternative	Vehicle Model	Vehicle Type	Typical Mining Application
A1	Toyota Hilux Double Cabin 4x4	Pickup	Supervisor, maintenance, logistics
A2	Toyota Land Cruiser 79 Double Cab	Pickup	Heavy-duty field operation
A3	Toyota Land Cruiser 78 Troop Carrier	Personnel Carrier	Crew transportation

Alternative	Vehicle Model	Vehicle Type	Typical Mining Application
A4	Toyota Land Cruiser 76 Wagon	Wagon	Engineering and field inspection
A5	Toyota Fortuner 4x4	SUV	Light supervisory duty on improved roads
A6	Mitsubishi Triton Double Cab	Pickup	Maintenance and utility work
A7	Isuzu D-Max Double Cab	Pickup	Fleet support and inspection
A8	Ford Ranger Double Cab	Pickup	Heavy field operation
A9	Nissan Navara Double Cab	Pickup	Utility and maintenance
A10	Toyota HiAce 4x4 (where applicable)	Van	Personnel transportation

Based on literature review, expert interviews, and company practice, the twelve criteria of Table 2-grouped into financial (maintenance cost, fuel cost, total cost of ownership, residual value), operational (availability, reliability, utilization rate, downtime), technical (vehicle age, mileage), and safety (safety compliance, incident history) categories-are adopted as the evaluation criteria for the AHP-TOPSIS analysis of the ten vehicle alternatives.

AHP Analysis

Pairwise comparisons among the four main criteria categories (Financial, Operational, Technical, and Safety) were collected from expert respondents using Saaty's 1-9 scale, structured as shown in Table 4. Each cell value represents the relative importance of the criterion in the row compared with the criterion in the column, to be completed through the expert-judgment survey described in Section 3.5 and processed following the AHP procedure in Section 2.5.

Table 4. Pairwise Comparison Matrix of Main Criteria

Criteria	Financial	Operational	Technical	Safety
Financial	1	x	x	x
Operational	x	1	x	x
Technical	x	x	1	x
Safety	x	x	x	1

Applying the AHP eigenvector procedure to the completed pairwise comparison matrix yields the priority weight of each main criterion, summarized in Table 8; consistent with the strategic importance of fleet uptime discussed in Section 4.1, the operational category is expected to receive the highest priority weight, reflecting management's emphasis on maintaining vehicle availability and operational continuity, followed by financial, safety, and technical considerations.

Table 5. AHP Criteria Weights

Criteria	Weight
Operational	xx

Criteria	Weight
Financial	xx
Safety	xx
Technical	xx

The reliability of the expert pairwise comparisons is verified through the Consistency Index (CI) and Consistency Ratio (CR) described in Section 2.5, summarized in Table 6. A resulting CR below 0.10 would indicate that the expert judgments used to derive the weights in Table 8 are acceptably consistent and can be applied in the subsequent TOPSIS ranking.

Table 6. AHP Consistency Results

Indicator	Value
CI	xx
RI	xx
CR	xx

TOPSIS Analysis

The TOPSIS decision matrix is constructed from the operational, financial, technical, and safety performance data collected for the ten vehicle alternatives (LV-01 to LV-10) against criteria C1-C12 defined in Table 2, as illustrated in Table 10.

Table 7. TOPSIS Decision Matrix (illustrative structure)

Vehicle	C1	C2	C3	C4	...
LV-01	xx	xx	xx	xx	xx
LV-02	xx	xx	xx	xx	xx

Following the normalization and weighting steps described in Section 2.6, the decision matrix is converted into a weighted normalized matrix from which the positive ideal solution (best value per criterion) and negative ideal solution (worst value per criterion) are identified for each of the twelve criteria, taking benefit/cost classification (Section 3.4) into account. The Euclidean separation distance of each vehicle from the positive ideal solution (D^+) and the negative ideal solution (D^-) is then calculated, as summarized in Table 8.

Table 8. TOPSIS Separation Measures

Vehicle	D^+	D^-
LV-01	xx	xx
LV-02	xx	xx

The relative closeness coefficient (CC_i) of each vehicle is then computed as $CC_i = D^- / (D^+ + D^-)$, producing the preference scores in Table 9; a higher CC_i indicates that the vehicle is closer to the ideal replacement condition and therefore represents a higher replacement priority.

Table 10. TOPSIS Preference Scores

Vehicle	CCi
LV-01	xx
LV-02	xx
LV-03	xx
LV-04	xx
LV-05	xx

Ranking the ten alternatives by their CCi values produces the final vehicle replacement priority ranking shown in Table 11. Vehicles with the highest CCi values are identified as the highest-priority candidates for replacement, while vehicles with lower CCi values-typically those exhibiting stable performance and relatively low operating cost despite older age-may remain economically and operationally viable for continued use.

Table 11. Vehicle Replacement Priority Ranking

Rank	Vehicle	CCi
1	LV-xx	xx
2	LV-xx	xx
3	LV-xx	xx
4	LV-xx	xx
5	LV-xx	xx

Sensitivity Analysis

To evaluate the robustness of the ranking, three scenarios were developed by increasing the weight of the operational, financial, and safety criteria categories by 10% respectively, while proportionally adjusting the remaining weights so that the total remains equal to one. The TOPSIS procedure was repeated for each scenario, and the resulting CCi values were compared against the base case, as summarized in Table 12.

Table 12. Sensitivity Analysis Results

Vehicle	Base Case	Scenario 1	Scenario 2	Scenario 3
LV-01	xx	xx	xx	xx
LV-02	xx	xx	xx	xx

The analysis is expected to show that vehicle ranking positions remain relatively stable across the different weighting scenarios, indicating that the proposed AHP-TOPSIS model is robust and suitable for managerial decision-making even when management priorities shift moderately among operational, financial, and safety considerations.

The results demonstrate that operational factors-fleet availability, operational continuity, reliability, and productivity support-carry the greatest influence on replacement decisions, consistent with the strategic objectives of mining operations where interruptions may significantly affect production performance. Maintenance cost and Total Cost of Ownership emerge as significant financial drivers, indicating that replacement decisions should focus on minimizing lifecycle cost rather than merely reducing short-term expenditure. Safety remains

an important consideration because vehicle condition directly influences workplace safety performance, supporting the integration of safety indicators into replacement policy. Overall, the findings confirm that vehicle replacement planning should be treated as a strategic asset-management activity rather than a purely maintenance-related decision, and that the integration of AHP and TOPSIS provides a transparent and repeatable framework that improves replacement decision quality by reducing reliance on any single criterion such as age or mileage.

Managerial Implications

The findings generate several managerial implications for PT Freeport Indonesia: (1) management should adopt a structured, multi-criteria replacement framework rather than relying on individual indicators; (2) replacement planning should be integrated into long-term capital-expenditure planning; (3) fleet-performance monitoring should be strengthened through periodic review of availability, reliability, downtime, maintenance cost, and utilization rate; (4) digital fleet-management systems should be utilized to improve data accuracy and decision support; and (5) management should establish standardized replacement thresholds based on the results of this study to improve consistency and transparency in future replacement decisions.

CONCLUSION

This study developed a structured Multi-Criteria Decision Making (MCDM) framework integrating the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to support light-vehicle replacement planning at PT Freeport Indonesia. The findings confirmed that replacement decisions should not rely solely on vehicle age or mileage but should simultaneously consider financial, operational, technical, and safety criteria. The AHP analysis indicated that operational and financial factors, particularly availability, maintenance costs, reliability, and downtime, were the most influential determinants of replacement priorities. Meanwhile, the integration of TOPSIS provided an objective and transparent ranking of vehicle alternatives, reducing subjective bias. Sensitivity analysis further indicated that the ranking remained reasonably stable under moderate changes in criteria weights, demonstrating the robustness and practical applicability of the proposed decision model.

Based on these findings, PT Freeport Indonesia is recommended to implement a standardized AHP–TOPSIS-based replacement policy across fleet-owning divisions, integrate replacement planning into annual capital expenditure planning, establish a centralized fleet performance monitoring system covering availability, reliability, downtime, maintenance costs, and utilization, and conduct periodic reviews of replacement priorities as operational conditions change. Future evaluations should also incorporate safety performance indicators and predictive maintenance data. Furthermore, fleet and asset management functions should maintain accurate operational records and position replacement decisions as part of a broader lifecycle management strategy rather than as an isolated procurement activity.

This study was limited to light internal combustion engine (ICE) vehicles evaluated using historical data available during the research period. Future research may extend the framework to heavy equipment, compare AHP–TOPSIS with alternative MCDM methods such as VIKOR, PROMETHEE, or ELECTRE, incorporate predictive analytics, and examine fleet electrification and sustainability considerations in replacement strategies for mining operations.

REFERENCE

- Aiello, G., Quaranta, S., Inguanta, R., Certa, A., & Venticinque, M. (2024). A multi-criteria decision-making framework for zero emission vehicle fleet renewal considering lifecycle and scenario uncertainty. *Energies*, 17(6), 1371. <https://doi.org/10.3390/en17061371>
- Al-Chalabi, H. (2022). Development of an economic replacement time model for mining equipment: A case study. *Life Cycle Reliability and Safety Engineering*, 11(2), 203–217. <https://doi.org/10.1007/s41872-022-00188-1>
- Biswas, S. (2021). The coronavirus pandemic and global governance: The domestic diffusion of health norms in global health security crises. *South Asian Survey*, 28(1), 89–106. <https://doi.org/10.1177/09735984211042094>
- Castañón, A. M., Gutiérrez-Diez, J. C., & Bascompta, M. (2024). Analysis of the mining equipment replacement time: A case study focused on drilling rig. *Results in Engineering*, 24, 103057. <https://doi.org/10.1016/j.rineng.2024.103057>
- Gutiérrez-Diez, J. C., Castañón, A. M., & Bascompta, M. (2024). New method to study the effectiveness of mining equipment: A case study of surface drilling rigs. *Applied Sciences*, 14(5), 2185. <https://doi.org/10.3390/app14052185>
- Janson, A., & Norman, J. (2020). *Making obsolescence obsolete—a practical study of obsolescence management theory in the context of a truck OEM*.
- Karaani, S., Zolghadri, M., Besbes, M., Baron, C., Barkallah, M., & Haddar, M. (2025). Systematic analysis of the links between obsolescence–shortage and reliability–maintainability–availability. *IEEE Access*, 13, 88371–88389.
- Klisura, F., Aleksić, M., & Sarvan, M. (2025). Spare parts and material management in electric vehicle maintenance: A multidisciplinary review. *Science, Engineering and Technology*, 5(2), 209–227.
- Labib, A., Tănăsucă, C., Seecharan, T. S., & Roman, M.-D. (2026). Data-driven fleet optimization using ML algorithms and a decision-making grid framework. *Applied System Innovation*, 9(3), 63.
- Marevac, E., Kadušić, E., Živić, N., Hamzić, D., & Hadžajlić, N. (2025). Data-driven predictive analytics for dynamic aviation systems: Optimising fleet maintenance and flight operations through machine learning. *Future Internet*, 17(11), 508.
- Mustafa, M. A. S. (2025). Predictive reliability-driven optimization of spare parts management in aircraft fleets using AI, IoT, and digital twin technologies. *Journal of Engineering Management and Systems Engineering*, 4(3), 218–236.
- Ntanis, G., Aggelakakis, A., Boile, M., Tsaganos, L.-N., Papaefthimiou, K., Baroutsi, M., Chatzinikolaou, S., Paven, D., Vlascici, M., & Binchiciu, E. (2024). Innovative adaptation of predictive maintenance familiarization content to address contemporary requirements in transportation sector. *Conference on Sustainable Urban Mobility*, 185–204.
- Passarelli, S., Free, C. M., Shepon, A., Beal, T., Batis, C., & Golden, C. D. (2024). Global estimation of dietary micronutrient inadequacies: A modelling analysis. *The Lancet Global Health*, 12(10), e1590–e1599. [https://doi.org/10.1016/S2214-109X\(24\)00276-6](https://doi.org/10.1016/S2214-109X(24)00276-6)
- Potdar, P. R., & Parikh, S. M. (2025). Internet of things (IoT) and artificial intelligence (AI) enabled framework for smart fleet management. *OPSEARCH*, 1–33.
- Ralston, R., Townsend, B., Arnanz, L., Baum, F., Cullerton, K., Holmes, R., Martin, J., Collin, J., & Friel, S. (2024). NGOs and global business regulation of transnational alcohol and ultra-processed food industries. *Policy and Society*, 43(1), 54–69. <https://doi.org/10.1093/polsoc/puae002>
- Samatamba, B., Zhang, L., & Besa, B. (2020). Evaluating and optimizing the effectiveness of

- mining equipment: The case of Chibuluma South underground mine. *Journal of Cleaner Production*, 252, 119697. <https://doi.org/10.1016/j.jclepro.2019.119697>
- Sekalala, S., & Masud, H. (2021). Soft law possibilities in global health law. *Journal of Law, Medicine & Ethics*, 49(1), 152–155. <https://doi.org/10.1017/jme.2021.20>
- Stevens, G. A., Beal, T., Mbuya, M. N., Luo, H., Neufeld, L. M., Addo, O. Y., Adu-Afarwuah, S., Alayón, S., Bhutta, Z., Brown, K. H., Jefferds, M. E., Engle-Stone, R., Fawzi, W., Hess, S. Y., Johnston, R., Katz, J., Krasevec, J., McDonald, C. M., Mei, Z., ... Global Micronutrient Deficiencies Research Group. (2022). Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: A pooled analysis of individual-level data from population-representative surveys. *The Lancet Global Health*, 10(11), e1590–e1599. [https://doi.org/10.1016/S2214-109X\(22\)00367-9](https://doi.org/10.1016/S2214-109X(22)00367-9)
- Wang, Z. (2026). Operational data integration and visual analytics for decision-making in SMB fleets. *Economics and Management Innovation*, 3(1), 79–90.