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A Study on the Implementation of Electric Vehicles as Technical Service Fleet at PT. PLN (Persero)

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Abstract: Indonesia is making the shift from fossil fuel-powered vehicles to electric vehicles due to technological advancements and the increasing demand for cleaner energy. Through Presidential Instruction No. 7 of 2022 concerning the Use of Battery Electric Vehicles as Operational and/or Official Vehicles for Central and Regional Government Institutions, the Indonesian government has taken action to hasten the adoption of battery electric vehicles. Similar difficulties are faced by PT. PLN (Persero), Indonesia's primary electricity supplier. Using electric vehicles as technical service vehicles is one calculated move that can be made. However, a thorough analysis is required to evaluate a number of factors, such as technical limitations, expenses, and suitable vehicle selection, prior to widespread deployment. The purpose of this study is to assess how PT. PLN (Persero) might use electric vehicles as technical service vehicles. In this study, the Analytical Hierarchy Process (AHP) and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) were combined to rank electric vehicle alternatives according to operational, technical, and financial criteria. Failure Mode and Effect Analysis (FMEA) was also used to identify potential failures and preventive measures. The findings indicate that FMEA can suggest a number of vehicle options based on the minimal requirements obtained from the Risk Priority Number (RPN) analysis. These specifications can then be used as a foundation for the creation of supporting electric vehicle charging station infrastructure and procurement tenders. Furthermore, Electric Vehicle A1 is the best choice for PLN's technical service fleet, according to the combination of AHP and PROMETHEE. By using these three strategies, the risk of failure is reduced, operational effectiveness is guaranteed, and the clean energy transition is supported in accordance with national policies and corporate goals.

Keywords: AHP, Electric Vehicles, FMEA, PROMETHEE, Technical Service Fleet

INTRODUCTION

One of the most important factors in the evolution of contemporary society is the advancement of transportation technology. However, there are a number of significant risks associated with the sharp rise in the number of vehicles that run on fossil fuels, including energy crises and pollution from carbon emissions that fuel climate change. With 3.8 billion barrels of oil reserves and 14 billion barrels of gas reserves [1], Indonesia is one of the oil and gasproducing nations, but it also suffers from the drawbacks of relying too heavily on fossil fuels. With the land transportation sector using almost 90% of fuel oil, the majority of which is subsidized by the government, Indonesia has become a net importer of crude oil since 2003 [2]. The realization of energy subsidies in 2023 reached IDR 159.6 trillion, with the largest share going to fuel and LPG subsidies, totaling IDR 95.6 trillion, according to Press Release No. 31.Pers/04/SJI/2024, issued January 15, 2024, by Minister of Energy and Mineral Resources Arifin Tasrif.

Furthermore, motor vehicles are the main source of pollution in major cities, where pollution indices surpass 50 AQI-US, indicating a continued decline in air quality. After the United States, the European Union, China, India, and Russia, Indonesia is the sixth-largest carbon emitter in the world, according to the World Resources Institute [3]. In addition to harming the environment, motor vehicle-related air pollution can lead to a number of health problems, including cancer, heart disease, and respiratory disorders [4]. Between 60% and 70% of the pollution in large cities comes from vehicle exhaust emissions, with the remaining portion coming from other sources like waste burning, industrial smokestacks, and forest fires [5].

One possible way to minimize air pollution, cut carbon emissions, and maximize the use of natural resources is to switch to electric vehicles from fossil fuel-powered ones. The shift to more sustainable mobility is anticipated to be supported by a number of industries, including the energy sector [6]. In order to encourage the use of electric vehicles, especially in the operations of government institutions, the government issued Presidential Regulation No. 55 of 2019 and Presidential Instruction No. 7 of 2022.

By integrating electric vehicles into its technical service operations, PT. PLN (Persero), a State-Owned Enterprise that oversees electricity management in Indonesia, strategically supports the energy transition. These vehicles assist with operations, network maintenance for electricity distribution, and customer service troubleshooting. In addition to potentially lowering the company's carbon footprint, switching to electric vehicles can also save long-term operating costs and show a dedication to sustainable technology.

To guarantee the program's viability, a thorough evaluation is necessary before electric vehicles can be used in technical service operations. In order to detect possible failures [7] in the electric vehicle program as PLN's technical service fleet and to identify preventive measures, like establishing the minimal requirements for electric vehicles and the necessary supporting infrastructure, this study incorporates the Failure Mode and Effect Analysis (FMEA) method. However, because it is assumed that the vehicles are defect-free and that vendors are required to provide replacement vehicles during maintenance or repairs, FMEA does not analyze vehicle damage. Each criterion is given a weight using the Analytical Hierarchy Process (AHP), which is a pairwise comparison rating system based on the Saaty scale [8]. The outranking approach, which precisely and thoroughly determines the quantitative value of each alternative, is used by the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) to objectively rank different electric vehicle options according to predetermined preferences [9]. By using this hybrid approach, the study hopes to support wise investment decisions and the shift to clean energy by offering the best suggestions for vehicle specifications and successful implementation techniques.

METHOD

A. Research Approach

A mixed methods approach is used in this study, integrating both qualitative and quantitative data. In order to obtain a thorough grasp of the possible deployment of electric vehicles as operational technical service vehicles at PT. PLN, this approach was selected. While qualitative data offers expert insights into the benefits and difficulties of integrating electric vehicles into PLN's operations, quantitative data is used to assess the cost-effectiveness of electric vehicle usage.

Data from technical service and distribution maintenance contracts served as the foundation for this study's quantitative methodology. Investment costs, vehicle operating and maintenance costs, and the history of vehicle usage (including distance driven, amount of cargo transported, fuel consumption, and operating hours) are all included in the quantitative data. The Network Division Manager at PT. PLN UP3 Yogyakarta is one of the experts who hold strategic roles in technical service operations, and several technical service personnel themselves are interviewed in-depth as part of the qualitative approach.

The state of the vehicles used for field technical services is directly monitored as part of the observation process. The vehicles, the equipment being transported, the amount of cargo space needed, and the vehicles' operating hours are all observed by the researcher. The purpose of this observation is to determine the technical and physical specifications of the vehicles and assess their performance in a range of operational scenarios.

B. Research Design

A case study design, a research technique that permits a thorough examination of a specific phenomenon within a particular context, is used in this study. Since the goal of this research is to precisely understand how the use of electric vehicles can be implemented in the technical service operations of a single business unit, the case study design was selected. This method also enables the researcher to consider technical, economic, and environmental aspects that affect how well and efficiently electric vehicles are implemented. Figure 1 below provides an example timeline of the research flow.:

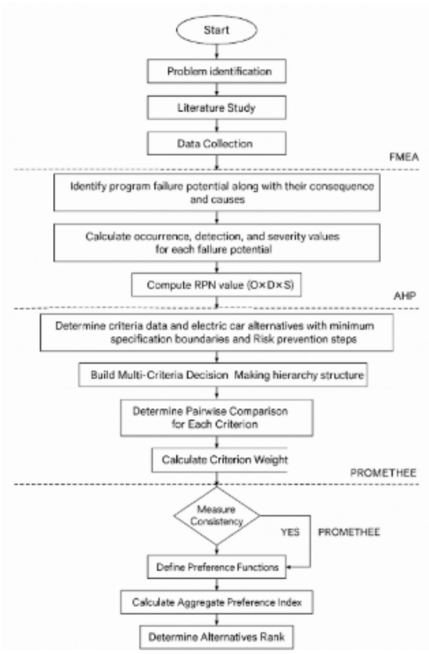

Figure 1. Research Flow

Population and Sample

All technical service vehicles working at PT. PLN ULP Yogyakarta City, which is distinguished by its urban lowland terrain, make up the study's population. According to the requirements specified in the operating contracts, the vehicles included in the population are Avanza cars of the station type. This particular unit was chosen because it had the most clients in PT. PLN UP3 Yogyakarta, a high workload, and consistent use that was fueled by the most service interruptions. A purposive sampling technique was used to select the research sample, concentrating on cars with the best performance in terms of fuel consumption and mileage (odometer reading). In order to gather the most pertinent and representative data about vehicle workload under fully operational conditions, this sampling technique was selected..

RESULT AND DISCUSSION

C. Cost Analysis

This cost study aims to ascertain the highest reasonable price for electric cars such that they do not surpass the company's budget over a three-year contract term. Comparing the total expenses of conventional vehicles and electric ones—including running, maintenance, and vehicle procurement costs—helps one to calculate.

Conventional Vehicle Costs

Conventional vehicles' running cost relies on fuel consumption. With data from PLN ULP Yogyakarta City, the Jogja 10 team notes the highest fuel consumption—545 liters per month. The total running cost over a three-year period is computed as follows given the present Pertalite price of IDR 10,000 per liter:

$$\text{Operational Cost} = 545 \times \text{Rp}10.000 \times 12 \times 3 = \text{Rp } 196.200.000$$

Regular six-month servicing, tire replacement, and battery replacement comprise the components of maintenance costs. Table 2 below shows the annual maintenance expenses, derived from the technical service contract between PLN and PT Haleyora Power.

Table 2. Conventional Vehicle Maintenance Costs

No	Item	Year 1	Year 2	Year 3
1	Battery Replacement	IDR 710,000	IDR 781,000	IDR 859,100
2	Tire Replacement	IDR 3,000,000	IDR 3,300,000	IDR 3,630,000
3	Service (every 6 months)	IDR 2,000,000	IDR 2,200,000	IDR 2,420,000
4	Total per Year	IDR 5,710,000	IDR 6,281,000	IDR 6,909,100

The whole maintenance costs over three years come to IDR 18,900,101. The components of the vehicle procurement cost consist in IDR 239,700,000, annual tax of 1.5% of the vehicle price for three years, and insurance of 3% of the vehicle price for three years. The whole procurement cost of the conventional car comes to IDR 272,059,500. Thus, the general cost of the conventional vehicle is:

$$\sum conventional\ vehicle = \sum B.OPS + \sum B.HAR + \sum B.Procurement$$

$$\sum conventional\ vehicle = 196.200.000 + 18.900.100 + 272.059.500$$

$$\sum conventional\ vehiclel = Rp\ 487.159.600$$

Electric Vehicle Costs

The three primary components of the cost analysis of electric vehicles are procurement, maintenance, and operating costs.

The energy consumption of an electric vehicle is used to calculate its operating cost. The greatest distance traveled during the study period was 3,773 km, per data from PLN ULP Yogyakarta City (Jogja Team 10, January 2024). Because battery electric vehicles (BEVs) use 13.1 kWh of energy every 100 kilometers [10], the monthly energy requirement is determined as follows:

$$Monthly\ Energy\ Requirement = \left(\frac{13{,}1x3773}{100}\right) = 494{,}41kWH$$

With the SPKLU electricity rate set at IDR 2,466.78 per kWh, the monthly operational cost is calculated as follows:

Monthly Operational Cost = 494.41 × 2,466.78 = IDR 1,219,601

The total operational cost over 3 years amounts to IDR 43,905,636, meaning that compared to fuel-powered vehicles, using electric vehicles reduces operational expenses by up to 77.6%.

Maintenance costs for electric vehicles are 40% lower than conventional vehicles [11], except for tire replacement. The estimated maintenance costs for electric vehicles are presented in Table 3.

Table 3. Electric Vehicle Maintenance Costs

No	Component	Year 1	Year 2	Year 3
1	Tire Replacement	IDR 3,000,000	IDR 3,300,000	IDR 3,630,000
2	Service (every 6 months)	IDR 1,626,000	IDR 1,788,600	IDR 1,967,460
3	Total per Year	IDR 4,626,000	IDR 5,088,600	IDR 5,597,460

Total maintenance costs over three years amount to Rp15,312,060.

The components of electric vehicle procurement costs include the purchase price of the vehicle (assumed as X), a tax of Rp140,000 due to a three-year subsidy [12], and vehicle insurance, which is calculated as 3% of the vehicle price over three years.

Total Electric Vehicle Procurement Cost = 1.09X + Rp420,00.

Maximum Price Limit for Electric Vehicles

The purchase cost ceiling for electric vehicles is determined by ensuring that the total operational, maintenance, and procurement costs are equivalent to the total cost of a conventional vehicle. This is demonstrated in the calculation below:

Total EV cost = Total cost of conventional vehicle

∑(Operational Cost EV) + ∑(Maintenance Cost EV) + ∑(Procurement Cost EV) = Rp487,159,600

Rp43,905,636 + Rp15,312,060 + 1.09X + Rp420,000 = Rp487,159,600

X = Rp392,221,930

Therefore, the maximum allowable purchase price for an electric vehicle—so that its total cost matches that of a conventional vehicle—is Rp392,221,930.

D. FMEA Analysis

Failure Mode and Effect Analysis (FMEA) is used to identify potential failures in the implementation of electric vehicles as technical service vehicles for PLN, as well as to determine the minimum vehicle specifications required. Potential failures in the use of electric vehicles were identified based on an interview with the Network Manager of PLN UP3 Yogyakarta, with the results presented in Table 4.

Table 4. Potential Failures

No.	Component / Function	Potential Failure	Cause of Failure	Potential Impact
1	Motor / Drives the vehicle	Unable to move while carrying equipment	Motor power is too low	Vehicle stops, service operations are disrupted
2	Battery / Stores energy, supplies energy to the electric motor	Battery runs out during operation	Battery capacity is too small	Delays in task completion

3	Battery Management System / Ensures proper battery charging process	Slow charging time	Does not support fast charging	Charging queue, technician frustration
4	Vehicle Trunk Volume / Stores tools and equipment	Unable to carry full work equipment, materials, and safety gear	Trunk space is too small	Work is hindered, worker safety is compromised
5	Charging Station (SPKLU) / Recharges the vehicle battery	Long charging duration	Only standard AC charging available	Report submission delays, charging queue, technician frustration
6	(Charging Station)	Charging queue	Number of charging stations is insufficient for fleet size	Report submission delays, charging queue, technician frustration
7	Repair Workshop / Vehicle damage repair	Difficulty accessing repair service	Limited technicians and spare parts	Longer repair time
8	Auxiliary Battery / Stores energy for accessories	Unable to power additional accessories like GPS or spotlights	No Vehicle-to-Load support, battery capacity too low	Work progress hindered
9	Vehicle Electrical Components / Powers the vehicle	Damaged by water puddles	Electrical components are not waterproof	Vehicle stops, service operations are disrupted
10	Charging App (SPKLU) / Digital payment for charging	Misuse of company funds by operators	No transaction monitoring system	Financial loss to the company

The deployment of electric vehicles faces a number of possible failure modes that could impact operations and service delivery, as indicated by the table of potential failures above. This emphasizes how crucial risk management, supporting infrastructure, and precise vehicle specification data are to the effective deployment of electric vehicles.

To determine the Risk Priority Number (RPN), values for Severity, Occurrence, and Detection were assigned to each identified potential failure during the expert interview. Table 5 below displays the results of the RPN calculation, with the list of possible failures arranged in order of the highest RPN values obtained from the expert interview.

Table 5. Failure Priority Based on RPN Calculation

No.	Potential Failure	Cause	S	O	D	RPN (S×O×D)
1	Difficulty in accessing repair workshops	Limited technicians & spare parts	9	8	8	576
2	Charging queue	Number of charging stations is insufficient for the fleet	5	4	8	160
3	Unable to move while carrying equipment	Motor power is too low	7	5	2	70

4	Long charging duration	Only standard AC-type charging stations available	2	7	4	56
5	Slow battery charging system	Battery Management System (BMS) does not support fast charging	2	6	3	36
6	Inability to carry work equipment, materials, and safety gear	Vehicle trunk is too small	3	3	3	27
7	Battery depletion during operations	Vehicle range is too short	3	3	2	18
8	Incompatibility with accessories like GPS or spotlights	No Vehicle-to-Load (V2L) support; auxiliary battery is too small	1	2	1	2
9	Damage due to water puddles	Electrical components are not waterproof	2	1	1	2
10	Misuse of digital payment funds by operators	Lack of transaction monitoring	2	1	1	2

Preventive actions were formulated in detail to address the root causes of failure. The following is an evaluation of the recommended preventive measures:

1. Difficulty in Accessing Workshops and Technicians
   a. Select vehicles with authorized dealerships located within a maximum travel radius of one hour.
   b. Dealerships must provide 24-hour service and offer training for PLN technicians to handle minor repairs.
   c. Vehicles must come with a minimum 3-year warranty to ensure the availability of spare parts.
2. Insufficient Number of Charging Ports (SPKL) Compared to Fleet Size
   d. The minimum number of SPKL ports required is calculated using the following approach:
      $\sum$ SPKL ports = ($\sum$ fleet) / ($\sum$ downtime > 30 minutes)
      30 minutes is the average charging time using an Ultra Fast Charging SPKL. If the operational fleet consists of 6 vehicles and each vehicle has downtime >30 minutes three times per shift, then:
      $\sum$ SPKL ports = 6 / 3 = 2 Ultra Fast Charging SPKL ports
   e. Implement a charging slot booking system for technical service teams.
   f. Develop internal SPKL facilities within PLN to support Yantek (Technical Service) operations.
3. Motor Power Too Low
   g. Set a minimum torque requirement of 122 Nm, equivalent to the specifications of a 1500cc LMPV, the current vehicle model that has proven capable of meeting operational needs.
4. Long Battery Charging Time
   h. Choose vehicles equipped with a Battery Management System (BMS) that supports fast charging (10–80% in 30 minutes).
   i. Use Ultra Fast Charging SPKLs with 50–150 kW capacity to reduce charging time.
5. Limited Cargo Capacity
   j. Storage volume with the second and third-row seats folded must be at least 586 liters, enough to store 37 work tools, 6 measuring instruments, 8 safety devices, and 8

personal protective equipment items. This capacity is based on usage data from the existing vehicle model.

6. Limited Battery Capacity Resulting in Short Driving Range
   k. The minimum driving range is calculated using the following approach: [calculation continuation to follow,

Driving Range Requirement

Driving Range = Maximum Daily Distance + 20% (SOC Limit for Fast Charging) + 20% (SOC Reserve for Emergency Trips to SPKLU) + 10% (Depreciation of Battery) The necessary electric vehicle range is determined as follows if the maximum daily distance during the study period was 121.71 km (Jogja Team 10, January 2024):

$X = 121.71 \text{ km} + 20\%X + 20\%X + 10\%X$

$X = 121.71 \text{ km} + 50\%X$

$X = 243.2 \text{ km}$

1. No V2L Support & Small Auxiliary Battery
   a. Select vehicles with V2L (Vehicle-to-Load) features to supply external power without affecting the main battery.
   b. Alternatively, choose vehicles with an auxiliary battery of at least 32Ah.
2. Electrical Components Not Water-Resistant
   a. Select vehicles with an IP67 certification (dust-tight and water-resistant up to 1 meter for 30 minutes).
3. No Monitoring of Charging Transactions
   a. Monitor each team's digital payment balance.
   b. Use postpaid applications to ensure transparent transactions.

E. Minimum Specifications for Electric Vehicles

Based on the evaluation of preventive measures against potential failures, the following minimum specifications are established for electric vehicles intended for PLN’s technical service operations:

1. Maximum price of Rp392,221,930
2. Authorized dealership within a one-hour travel radius and 24-hour service availability
3. Minimum torque of 122 Nm
4. Fast charging capability
5. Luggage capacity of at least 586 liters with the 2nd and 3rd rows folded
6. Minimum driving range of 243.2 km (WLTP) or 291.84 km (NEDC test), considering that fuel consumption under WLTP testing is on average 20% higher [13]
7. V2L feature or a minimum auxiliary battery capacity of 32Ah
8. Electrical components certified with IP67 rating (water- and dust-resistant)

From the selection of electric vehicles available in Indonesia, specifically in Yogyakarta in 2024, five vehicle alternatives were identified that meet these specifications, as shown in Table 6,

Table 6. Selected Electric Vehicle Alternatives

Specification	BYD M6 Standard (A1)	BYD Dolphin Dynamic (A2)	Wuling Bingou LR (A3)	Wuling Bingou Premium (A4)	DFSK Gelora EV (A5)
Price (IDR)	379 million	365 million	326 million	372 million	350 million
Torque (Nm)	310	180	150	150	200

Battery Capacity (kWh)	55.4	44.9	31.9	37.9	42
Range (km) – WLTP	350	342	278	342	250
DC Charging Time (10–80%)	26.14 minutes	31.43 minutes	22.33 minutes	26.53 minutes	44.10 minutes
Cargo Space (liters)	2300	1310	790	790	4800
V2L / Auxiliary Battery	V2L	V2L	32Ah Battery	32Ah Battery	40Ah Battery
Showroom Type	3S	3S	3S	3S	3S

Source: Compiled from various sources, websites, and interviews (2024).
3S: Sales, Service, Spare Parts

F. AHP Analysis

Determining the objective, standards, and options for choosing an electric vehicle to be utilized as an operational vehicle by PT PLN (Persero) is the first stage in the Analytical Hierarchy Process (AHP). The goal is to identify the best electric car according to the given standards. Table 6 lists the available vehicle options, and Table 7 displays the selection criteria that were obtained from expert interviews.

Table 7. Identification of Criteria

Criteria	Unit	Type of Criteria	Description
Torque	Newton meter (Nm)	Benefit	The rotational force generated by the engine.
Battery Capacity	Kilowatt hour (kWh)	Benefit	Affects the driving range and duration of vehicle usage.
Cargo Volume	Liter (L)	Benefit	Cargo space capacity when the seats are folded down.
Driving Range	Kilometer (Km)	Benefit	The maximum distance the vehicle can travel on a single full charge.
Fast Charging Time	Minute	Cost	The time required to rapidly charge the vehicle's battery.
Purchase Price	IDR	Cost	The initial expense for acquiring the electric vehicle.

The AHP hierarchical structure can be observed in Figure 2.

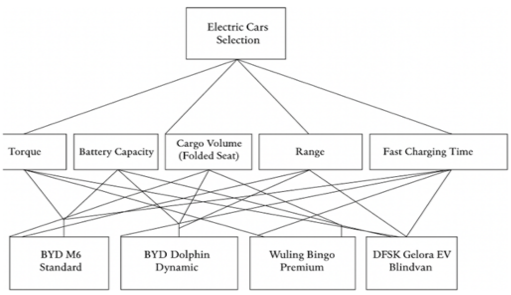

Figure 2. AHP Hierarchical Structure for Electric Vehicle Selection

The electric vehicle selection process begins with pairwise comparisons of the main criteria. The evaluation was conducted by the Network Manager of PLN. This analysis produces priority weights for each criterion.

Table 8. Pairwise Comparison Matrix

Criteria	Torque	Battery Capacity	Cargo Volume	Driving Range	Fast Charging Time	Price
Torque	1	0.33	3	0.14	3	5
Battery Capacity	3	1	3	1	3	3
Cargo Volume	0.33	0.33	1	0.14	0.33	1
Driving Range	7	1	5	1	5	5
Fast Charging Time	0.33	0.33	3	0.20	1	3
Price	0.20	0.33	1	0.20	0.33	1
Total	11.87	3.33	16	2.69	12.67	18

Each element in the matrix is divided by the total sum of its respective column to obtain the normalized values, as shown in Table 9.

Table 9. Normalized Matrix Results

Criteria	Torque	Battery Capacity	Cargo Volume	Driving Range	Fast Charging Time	Price
Torque	0.08	0.10	0.19	0.05	0.24	0.28
Battery Capacity	0.25	0.30	0.19	0.37	0.24	0.17
Cargo Volume	0.03	0.10	0.06	0.05	0.03	0.06
Driving Range	0.59	0.30	0.31	0.37	0.39	0.28
Fast Charging Time	0.03	0.10	0.19	0.07	0.08	0.17
Price	0.02	0.10	0.06	0.07	0.03	0.06

The eigenvector values can be calculated by taking the average of each row in the normalized matrix, which is then used to determine the weight of each criterion. The results of the eigenvector calculation in this study are presented in Table 10.

Table 10. Eigenvector Results

Criteria	Torque	Battery Capacity	Cargo Volume	Driving Range	Fast Charging Time	Price
Eigen Vector	0.16	0.25	0.05	0.37	0.11	0.06

After determining the weight of each criterion, the next step is to test the consistency to ensure that the assessments are not random or inconsistent. This involves the following stages.

1. Calculating the Eigen Matrix, which is done by multiplying the pairwise comparison matrix by the vector of criterion weights to evaluate the consistency of relationships among the criteria. The results of the eigen matrix calculation are presented in Table 11.

Table 11. Eigen Matrix Calculation Results

Criteria	Torque	Battery Capacity	Cargo Volume	Driving Range	Fast Charging Time	Price
Torque	0.16	0.08	0.16	0.05	0.32	0.28

Battery Capacity	0.47	0.25	0.16	0.37	0.32	0.17
Cargo Volume	0.05	0.08	0.05	0.05	0.04	0.06
Driving Range	1.10	0.25	0.27	0.37	0.53	0.28
Fast Charging Time	0.05	0.08	0.16	0.07	0.11	0.17
Price	0.03	0.08	0.05	0.07	0.04	0.06

2. M Calculating the Weighted Sum Value and Eigenvalue, where each row in the eigen matrix is summed per criterion and then divided by the corresponding criterion weight to obtain the eigenvalue. The calculation results are shown in Table 12.

Table 12. Eigenvalue Calculation Results

Criteria	Torque	Battery Capacity	Cargo Volume	Driving Range	Fast Charging Time	Price
Weighted Sum	1.05	1.75	0.34	2.80	0.65	0.34
Criterion Weight	0.16	0.25	0.05	0.37	0.11	0.06
Eigenvalue	6.74	6.91	6.18	7.49	6.12	6.01

3. Calculating the Maximum Eigenvalue

$$\lambda_{max} = \frac{\sum Eigen\,Value}{n}$$

$$\lambda_{max} = \frac{(6{,}74 + 6{,}91 + 6{,}18 + 7{,}49 + 6{,}12 + 6{,}01)}{6}$$

$$\lambda_{max} = 6{,}57$$

4. Calculating the Consistency Index (CI)

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{6{,}57 - 6}{6 - 1} = 0{,}114$$

5. Calculating the Consistency Ratio (CR)

$$CR = \frac{CI}{RI}$$

$$CR = \frac{CI}{RI} = \frac{0{,}114}{1{,}24} = 0{,}09$$

Tabel 13 Random Indeks

Order Matrix	1	2	3	4	5	**6**	7	8	9	10
Random Index	0	0	0,58	0,90	1,12	**1,24**	1,32	1,41	1,45	1,49

Since the CR value is ≤10%, the comparison matrix is considered consistent.

G. PROMETHEE Analysis

The PROMETHEE I and II methods are used to objectively compare electric vehicle options based on predefined preferences. The alternative data and the weights of each criterion are presented in Table 14.

Table 14. Criteria and Alternative Data

Criteria	Weight	Type	A1	A2	A3	A4	A5
Total Torque (Nm)	0.16	Benefit	310	180	150	150	200
Battery Capacity (kWh)	0.25	Benefit	55.4	44.9	31.9	37.9	42

Cargo Volume (liters)	0.05	Benefit	2300	1310	790	790	4800
Driving Range (km)	0.37	Benefit	350	342	278	342	250
Fast Charging Time (min)	0.11	Cost	26.1	31.4	22.3	26.5	44.1
Price (million IDR)	0.06	Cost	379	365	326	372	350

This study uses a linear preference function to proportionally assess differences in criteria, ensuring more accurate and fair results. The preference function is represented by the following equation.

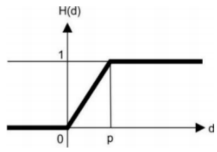

Figure 3. Linear Preference Function with Parameter p

H(d): Difference function between criteria across alternatives
d: Difference in criterion value { d = f(a) − f(b) }
p: Preference threshold
The value of p (preference threshold) is determined using the maximum–minimum range method, calculated as.

$$p = 0.2 \times (\text{maximum} - \text{minimum})$$

Table 15. Preference Threshold Values

Criteria	Maximum	Minimum	p = 0.2 × (Max − Min)
Total Torque (Nm)	310	150	32
Battery Capacity (kWh)	55.4	31.9	4.7
Cargo Volume (liters)	4800	790	802
Driving Range (km)	350	250	20
Fast Charging Time (min)	44.1	22.3	4.4
Purchase Price (million IDR)	379	326	10.6

The preference function is calculated by comparing the difference in values between alternatives and their respective preference thresholds, as shown in Figure 3. An example of preference function calculation for Total Torque between A1 and A2.

$$d = 310 - 180 = 130 \text{ Nm, with } p = 32 \text{ Nm}$$

Since d > p, the preference function value of A1 over A2 for the torque criterion is H(d) = 1. All preference index calculation results are presented in Table 16.

Table 16. Preference Function Results

Alternative	Total Torque	Battery Capacity	Cargo Volume	Driving Range	Fast Charging Time	Purchase Price
A1–A2	1	1	1	0.4	1	0
A2–A1	0	0	0	0	0	1
A1–A3	1	1	1	1	0	0
A3–A1	0	0	0	0	0.86	1
A1–A4	1	1	1	0.4	0.09	0
A4–A1	0	0	0	0	0	0.66
A1–A5	1	1	0	1	1	0
A5–A1	0	0	1	0	0	1
A2–A3	0.94	1	0.65	1	0	0
A3–A2	0	0	0	0	1	1
A2–A4	0.94	1	0.65	0	0	0.66

A4–A2	0	0	0	0	1	0
A2–A5	0	0.62	0	1	1	0
A5–A2	0	0	1	0	0	1
A3–A4	0	0	0	0	0.95	1
A4–A3	0	1	0	1	0	0
A3–A5	0	0	0	1	1	1
A5–A3	1	1	1	0	0	0
A4–A5	0	0	0	1	1	0
A5–A4	1	0.87	1	0	0	1

Subsequently, the aggregated preference index is calculated using the following equation:

$$\pi(A_1, A_2) = \sum_{j=1}^{k} Pj\,(A_1, A_2)xWj$$

Pj (A1,A2) : the preference function value for each criterion
Wj : the weight of each criterion
K : the total number of criteria.
Here is an example of the aggregated preference index calculation for A1 over A2.

$$\pi(A_1, A_2) = (1x0{,}16) + (1x0{,}25) + (1x0{,}05) + (0{,}4x0{,}37) + (1x0{,}11) + (0x0{,}06)$$

$$\pi(A_1, A_2) = 0{,}16 + 0{,}25 + 0{,}05 + 0{,}148 + 0{,}11 + 0 = 0{,}718$$

Table 17. Aggregated Preference Index Results

Alternative	Preference Index		Alternative	Preference Index
A1–A2	0.718		A2–A4	0.472
A2–A1	0.060		A4–A2	0.110
A1–A3	0.830		A2–A5	0.634
A3–A1	0.155		A5–A2	0.110
A1–A4	0.618		A3–A4	0.165
A4–A1	0.039		A4–A3	0.620
A1–A5	0.890		A3–A5	0.540
A5–A1	0.110		A5–A3	0.460
A2–A3	0.802		A4–A5	0.480
A3–A2	0.170		A5–A4	0.488

The next step in the outranking method is calculating the preference differences among all alternatives to derive the final ranking based on the net flow values. As an illustration, the following is an example of the net flow calculation for A1. Leaving Flow (Φ^+) or Positive Outranking for A1:

$$\Phi^+(A_1) = \frac{1}{n-1} \sum_{x \in A} \pi(A_1, x)$$

Where *n* is the number of alternatives and π(A1, x) is the aggregated preference index between A1 and each alternative.

$$\Phi^+(A_1) = \frac{1}{5-1}(0{,}718 + 0{,}83 + 0{,}618 + 0{,}89)$$

$$\Phi^+(A_1) = \frac{1}{4}(3{,}056) = 0{,}764$$

Entering Flow (Φ^-) or Negative Outranking for A1 :

$$\Phi^-(A_1) = \frac{1}{n-1} \sum_{x \in A} \pi(x, A_1)$$

$$\Phi^{-}(A_1) = \frac{1}{5-1}(0{,}06 + 0{,}155 + 0{,}039 + 0{,}11)$$
$$\Phi^{-}(A_1) = \frac{1}{4}(0{,}364) = 0{,}091$$

Thus, the Net Flow (Φ) value for A1 is,

$$\Phi(A_1) \quad = \Phi^{+}(A_1) - \Phi^{-}(A_1) = 0{,}764 - 0{,}091 = 0{,}673$$

This process is repeated for all alternatives and summarized in Table 18. The alternative with the highest Net Flow (Φ) is selected as the best option.

Table 18. Ranking Results

Alternative	Outranking^{+}	Outranking^{-}	Net Flow	Ranking
A1	0.7640	0.0910	0.6730	1
A2	0.4921	0.2770	0.2151	2
A3	0.2775	0.6780	–0.4005	5
A4	0.3123	0.4358	–0.1235	3
A5	0.2920	0.6561	–0.3641	4

Alternative A1 has the highest Net Flow value of 0.6730, making it the top-ranked electric vehicle alternative for PT PLN (Persero)'s technical service operations. A sensitivity analysis was not conducted due to the significant deviation between rankings, with an average difference of approximately 66%, indicating that minor data changes are unlikely to affect the ranking results.

CONCLUSION

1. The FMEA study effectively identified a number of barriers to PLN's adoption of electric vehicles, including the risk of power outages (RPN: 18), the difficulty in reaching repair workshops (RPN: 576), the long lines at public charging stations (RPN: 160), the limited cargo capacity (RPN: 27), and the difficulty in accessing repair workshops.
2. Fast-charging capability, torque of at least 122 Nm, cargo capacity of at least 586 liters, a driving range of at least 243.2 km (WLTP), a V2L feature or a battery of at least 32AH, IP67 standard, a maximum price of IDR 392 million with a minimum warranty of three years, and the availability of authorized service centers within an hour's travel radius are the minimum requirements for electric vehicles.
3. The top option for PLN's technical service electric vehicle is Alternative A1 or BYD M6 Standard, which received the highest net flow score.
4. Since electric vehicles improve operational efficiency, lower long-term costs, and aid in the country's energy transition, their deployment is deemed feasible.
5. The FMEA, AHP, and PROMETHEE methods worked well together to finish this study.

SUGGESTIONS

1. To support the seamless operation of electric vehicles, PLN should make sure that there is an adequate infrastructure for electric vehicle charging stations (EVCS).
2. A thorough Standard Operating Procedure (SOP) needs to be created for electric vehicle upkeep, operation, and troubleshooting.
3. To evaluate the adoption of electric vehicle technology in various operational regions, periodic assessments and additional research ought to be carried out.
4. To guarantee after-sales service, spare parts availability, and round-the-clock emergency support, partnerships with authorized dealers should be maximized.
5. By negotiating bulk orders, large-scale procurement can assist in lowering unit prices.

6. Premium features that don't significantly affect operational performance, like alloy wheels, keyless entry, retractable mirrors, engine start-stop buttons, premium head units, adaptive cruise control, electric seats, and sunroofs, can be removed to reduce costs without sacrificing the vehicle's essential functions.

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