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Dual-Stage AHP-TOPSIS Approach for AMI Communication Technology Selection in TMCS

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Reliable communication infrastructure is essential for electric vehicle (EV) charging systems, particularly in Truck Mobile Charging Stations (TMCS), where operational and billing data must be securely transmitted to utility data centres through Advanced Metering Infrastructure (AMI). Selecting an appropriate communication technology for AMI in TMCS is challenging because multiple technical criteria must be evaluated simultaneously. This study proposes a dual-stage 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 assess candidate communication technologies. Four criteria are considered: data rate, battery lifespan, latency, and communication range. AHP determines the relative importance of these criteria, while TOPSIS ranks five Low Power Wide Area Network (LPWAN) technologies: NB-IoT, LTE-M, LoRaWAN, Weightless, and Wi-SUN. Results show that communication range is the most influential criterion (weight = 0.507), followed by data rate, battery lifespan, and latency. LTE-M achieves the highest closeness coefficient (0.89) and is identified as the most suitable technology. Sensitivity analysis confirms the robustness of the ranking results.

Keywords: AMI Communication; TMCS; AHP; TOPSIS

I. INTRODUCTION

In recent years, electric vehicles (EVs) have emerged as a promising solution for reducing greenhouse gas emissions and mitigating environmental pollution in the transportation sector (Buekers *et al.*, 2014; Ferrero *et al.*, 2016). The rapid growth of EV adoption reflects the global transition toward sustainable mobility and low-carbon energy systems. According to the International Energy Agency, the global EV market is expected to reach approximately 140 million vehicles by 2030, with annual sales projected to exceed 25 million units. In 2022 alone, EVs accounted for approximately 14% of global car sales, representing a significant increase compared to previous years (International Energy Agency, 2024)(Buekers *et al.*, 2014; Ferrero *et al.*, 2016; International Energy Agency, 2024).

The rapid growth of electric vehicles (EVs) is transforming modern transportation systems and accelerating the transition toward sustainable energy infrastructures from 20 billion kWh in 2020 to 280 billion kWh by 2030 (Engel *et al.*). The demand for reliable and flexible charging infrastructure has become increasingly critical. Among these alternatives, mobile EV charging systems (MCS) have gained increasing attention due to their flexibility, mobility, and ability to provide on-demand charging services in various scenarios, including emergency situations and locations with limited charging infrastructure (S. Afshar *et al.*, 2020; Saboori *et al.*, 2021)(S. Afshar *et al.*, 2020). Mobile charging systems can generally be classified into three categories: Truck Mobile Charging Stations (TMCS), Portable Mobile Charging Stations (PMCS), and Vehicle-to-Vehicle (V2V) power transfer systems. Among these solutions, TMCS has

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*Corresponding author's e-mail: uki@pcr.ac.id emerged as the most widely implemented technology due to its ability to deliver high charging capacity and operational flexibility.

The effectiveness of TMCS depends not only on power delivery capability but also on the quality of its communication infrastructure supported by AMI (J. Jaskolka, 2018). AMI also enables real-time monitoring, data collection, and control of EV charging activities, making it an essential component of modern smart grid environments (Lam *et al.*, 2011).

However, selecting an appropriate communication technology for AMI deployment in mobile charging systems presents significant challenges due to diverse technical requirements including communication range, latency, data transmission capacity, and energy efficiency (Bian *et al.*, 2019; Kuzlu *et al.*, 2014; R. D. Rahayani & N. -K. C. Nair, 2021). Several communication technologies have been proposed for EV-related applications, including cellular networks such as 2.5G, 3G, 4G, and 5G, as well as various wireless communication solutions (Bayram & Papapanagiotou, 2014a; Fuentes *et al.*, 2020).

Recent advances in Internet of Things (IoT) and smart grid communication have introduced several promising candidates for AMI deployment. In particular, Low Power Wide Area Network (LPWAN) technologies have emerged as strong alternatives because they are designed to support long-range communication with relatively low power consumption and low infrastructure burden. Technologies such as NB-IoT, LTE-M, LoRaWAN, Weightless, and Wi-SUN offer different technical trade-offs in terms of data rate, latency, battery life, and communication range (Mekki *et al.*, 2019; Raza *et al.*, 2017). Although these technologies have been widely discussed in smart metering, IoT, and smart grid applications (R. D. Rahayani & N. -K. C. Nair, 2021; Rinaldi *et al.*, 2018), their suitability for AMI implementation in TMCS remains insufficiently examined through a structured evaluation framework.

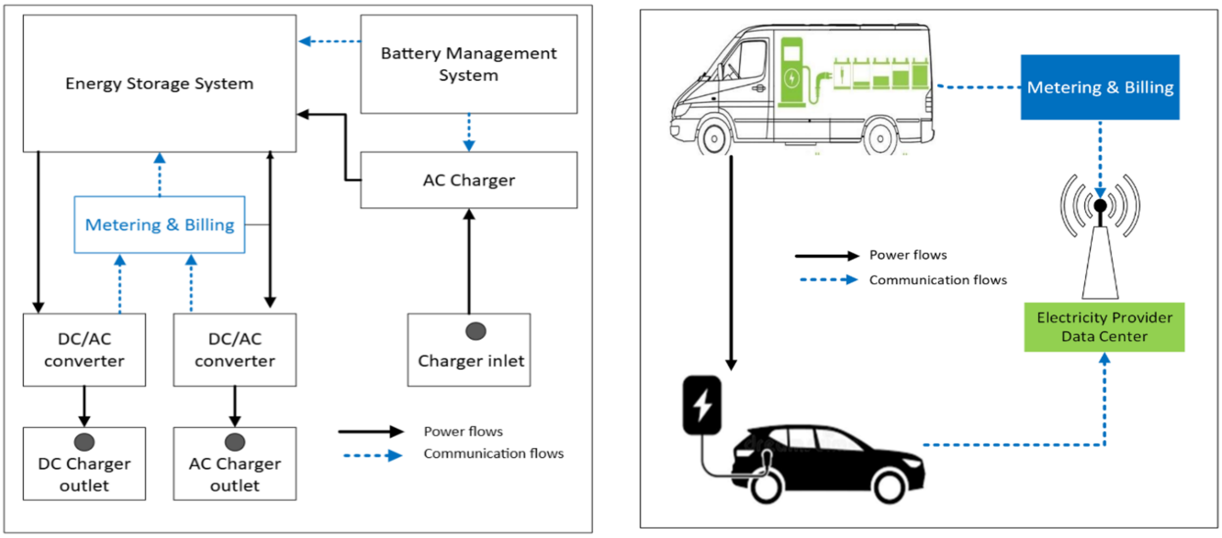
Despite the growing availability of LPWAN communication technologies, Selecting the most appropriate communication technology for TMCS is a complex multi-criteria decision-making problem, as multiple technical parameters must be considered simultaneously. These parameters typically include data rate, communication range, latency, reliability, and energy efficiency, which often involve trade-offs among competing performance objectives. In such situations, Multi-Criteria Decision-Making (MCDM) techniques provide a structured framework for evaluating alternatives based on multiple criteria.

MCDM techniques have been widely applied to engineering decision-making problems in which multiple conflicting criteria must be considered simultaneously (Gazi *et al.*, 2026). Among these techniques, the Analytic Hierarchy Process (AHP) is commonly used to determine the relative importance of decision criteria through pairwise comparisons (Leal, 2020; Saaty, 1990), while the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) provides a systematic approach to ranking alternatives based on their distance from ideal and negative-ideal solutions (Hwang & Yoon, 1981; Saaty, 1990). Other MCDM techniques, such as Simple Additive Weighting (SAW), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) have been widely used due to their capability to evaluate alternatives based on multiple criteria and expert judgments (Abdullah *et al.*, 2019; Anojkumar *et al.*, 2014; Ciardiello & Genovese, 2023; Gul *et al.*, 2018)

Although previous studies demonstrate the effectiveness of MCDM methods for infrastructure evaluation, several limitations remain. First, some approaches rely on subjective weighting without consistency validation, which may reduce the reliability of the decision results. Second, several studies focus only on ranking methods without systematically determining the relative importance of criteria. Third, limited research specifically addresses communication technology selection for AMI within TMCS environments using an integrated decision-making framework.

To address this gap, this study proposes a dual-stage decision-making framework integrating AHP and TOPSIS to evaluate and rank LPWAN communication technologies for AMI implementation in Truck Mobile Charging Stations. The proposed framework first determines the relative importance of key communication performance criteria using the AHP method and subsequently ranks alternative communication technologies using TOPSIS based on their proximity to the ideal solution.

The selection of AHP and TOPSIS is motivated by several methodological advantages. AHP provides a structured mechanism for deriving criteria weights while ensuring the consistency of expert judgments. Meanwhile, TOPSIS provides an effective ranking approach by evaluating the relative distances of alternatives from both the ideal and negative-ideal solutions, enabling an objective comparison among competing technologies. The integration of these two techniques allows the decision model to combine consistent criteria weighting with robust alternative ranking, thereby improving the reliability of the evaluation process.



(a) (b)

Figure 1. (a) Architecture of MCSs ; (b) MCS communication flow

To validate the effectiveness of the proposed model, the ranking results from AHP–TOPSIS were compared with those from AHP–SAW and AHP–PROMETHEE. The comparison shows that although the general ranking trend remains consistent, the AHP–TOPSIS model provides clearer separation between alternatives due to its distance-based evaluation mechanism.

The main contributions of this study are summarised as follows:

1. Development of a dual-stage MCDM framework integrating AHP and TOPSIS for communication technology selection in TMCS.
2. Identification and evaluation of critical AMI communication parameters including data rate, battery lifespan, latency, and communication range.
3. Comparative validation of the proposed model using AHP-SAW and AHP-PROMETHEE methods.
4. Demonstration of a robust and computationally efficient decision model for smart grid communication planning.

The results of this study provide practical insights for EV infrastructure planners, smart grid developers, and charging network operators in selecting appropriate communication technologies for mobile charging applications. In addition, the proposed decision-support framework can be extended to evaluate communication technologies in other emerging smart energy systems.

The remainder of this paper is organised as follows. Section 2 discusses the related work, while section 3 presents the proposed AHP–TOPSIS decision-making methodology. Section 4 discusses the results and evaluation of communication technology alternatives. Finally, Section 5 concludes the paper and outlines directions for future research.

II. RELATED WORK

A. *Advance Metering Infrastructure in TMCS*

A TMCS is an electric or dual-stage vehicle equipped with multiple charging outlets that provide EV users with flexible charging services anytime and anywhere. Figure 1(a) describes the architecture of the Mobile Charging Station (MCS), including the energy storage system, battery management system, AC/DC converters, and charging outlets. Figure 1(b) presents the communication flow between the TMCS and the electricity provider's data centre through the AMI network. The dashed arrows represent communication data flow, while solid lines represent power flow.

During operation, the electrical energy consumed by connected EVs is measured and transmitted to the TMCS operator through AMI for monitoring, metering, and billing purposes (Atmaja & Amin, 2015; Beyazıt & Taşcıkaraoğlu, 2023).

Figure 1 also illustrates the communication flow between the TMCS and the electricity provider's data centre, highlighting the integration of power delivery and communication systems within the overall Mobile Charging Station (MCS) architecture. This integration enables real-time monitoring and control of charging activities, which is essential for efficient energy management and operational transparency.

Despite its importance, many current TMCS implementations lack fully integrated AMI communication modules. This limitation presents an opportunity for system designers and operators to strategically select the most suitable communication technologies to ensure reliable connectivity between EVs, the TMCS platform, and the power utility's data infrastructure.

The telecommunication network plays a significant role in determining the operational cost and performance of Mobile Charging Stations (MCS) (Kozyra, 2023). By deploying an adaptive and cost-efficient communication infrastructure, operators can improve network reliability while reducing operational expenses. Furthermore, the selection of communication technology directly affects several key performance parameters, including data rate, coverage range, latency, and power consumption, which in turn influence the overall efficiency of MCS operation.

Efficient power consumption is particularly important for extending the lifetime of communication devices and reducing operational costs. At the same time, an adequate data rate is required to ensure reliable transmission of charging information from the MCS to the utility data centre. In addition, the AMI communication network in MCS environments is highly sensitive to latency, which refers to the time delay between data transmission and reception (Marinšek *et al.*, 2021). Excessive latency may disrupt communication between the charging station and the power utility, potentially affecting monitoring and billing processes.

Another critical technical requirement for telecommunication networks in mobile charging systems is coverage. The network must provide sufficient geographic coverage across all potential MCS deployment locations to ensure uninterrupted transmission of charging data regardless of the station's operating environment.

AMI has specified network requirements (Abrahamsen *et al.*, 2021; M. Ghorbanian *et al.*, 2019; R. D. Rahayani & N. -K. C. Nair, 2021) to facilitate seamless data transfer to the data centre. These requirements support effective communication, contributing to the overall reliability and performance of the AMI. The technical requirements for AMI communication are shown in Table 1.

Table 1. Technical Requirements for AMI Communication

Parameter	**Specification**
Data rate	10 -100 kbps/node 500 kbps for backhaul
Data size	More than 100 bytes
Latency	2-5 s
Reliability	99-99.99%
Security	High

Conventional wireless communication technologies, such as cellular networks and Wi-Fi, present several limitations when applied to truck mobile charging stations. These limitations include high power consumption, high

Table 2. Technical Features of AMI Network Candidates

Alternatives	Data rate (kbps)	Battery life (year)	Latency (s)	Range (km)	Channel Access Method
NB-IoT	~100	>10	2-10	≤ 10 km for both urban and rural	TDMA/FDMA
LTE-M	370-1000	5-10	0.01-0.02	≤ 10 km both urban and rural	TDMA/FDMA
LoRa WAN	50	5-10	1-16 s	≤ 2 km in urban ≤ 10 km in rural	ALOHA
Weightless	≤ 100 kbps	≤ 15	2-10 s	8-10 km for both urban and rural	TDMA/FDMA
Wi-SUN	50-300	≤ 15	0.02-1 s	4 km in urban 10 km in rural	FHMA

operational costs, and limited coverage, which reduce their effectiveness in large-scale, geographically widespread deployments.

To overcome these challenges, Low Power Wide Area Network (LPWAN) technologies have emerged as a more suitable and cost-efficient alternative. LPWAN networks are specifically designed to support long-range communication—typically 5-15 km—while maintaining low power consumption and minimal infrastructure requirements. These characteristics make LPWAN technologies particularly well-suited for AMI communication systems and large-scale oT-based infrastructure, where long device lifetime, wide coverage, and network scalability are essential.

Table 2 summarises the technical specifications of several widely adopted LPWAN technologies, highlighting their potential suitability for TMCS communication applications.

Since each LPWAN technology exhibits different strengths and limitations across multiple technical parameters, selecting the most suitable communication technology for TMCS deployment becomes a complex multi-criteria decision problem. Therefore, a systematic evaluation approach is required to assess these technologies simultaneously against multiple performance criteria.

B. Multi-Criteria Decision-Making for Communication Technology Selection

Because communication technology selection involves multiple conflicting criteria, several researchers have adopted Multi-Criteria Decision-Making (MCDM) methods. (Abdul & Wenqi, 2022) applied fuzzy TOPSIS to evaluate communication technologies for smart-grid use and argued that a decision framework is needed when technologies differ across multiple criteria. Similarly, (Abdulsalam *et al.*, 2023) presented an overview and multicriteria analysis of communication technologies for smart-grid applications and concluded that technology selection requires compromise across performance dimensions rather than reliance on a single metric. These studies are important because they confirm that communication technology evaluation in the smart-grid domain is inherently multi-criteria. They also show that ranking-based decision support can improve transparency in technology selection. However, the existing MCDM literature still leaves several gaps relative to the needs of this study. First, prior communication technology evaluations are generally framed in a broad sense for smart grids rather than for the specific operational setting of TMCS. Second, some studies emphasise alternative ranking but do not clearly separate the criteria-weighting stage from the ranking stage in a transparent sequential structure. Third, comparative validation across multiple decision models remains limited in this domain. As a result, the literature does not yet offer a focused dual-stage MCDM framework for selecting AMI communication technologies in TMCS environments. The comparison of related studies and the present work is summarised in Table 3.

Table 3. Comparison of related studies and the present work

Study	Main focus	Method / approach	Key evaluation dimensions	Main limitation relative to this study
(Afshar *et al.*, 2021)	Mobile charging stations for EVs	Review	Charging flexibility, utilisation, grid impact	Does not address AMI communication technology selection.
(Bayram & Papapanagiotou, 2014b)	Communication technologies for the Internet of Electric Vehicles	Survey / review	EV-grid communication requirements, standards, candidate technologies	Not specific to TMCS and does not provide a formal ranking model
(Kuzlu *et al.*, 2014)	Smart-grid communication requirements	Survey / requirement analysis	Payload, latency, reliability, HAN/NAN/WAN architecture	Broad smart-grid scope, not specific to TMCS-based AMI
(Mekki *et al.*, 2019; Raza *et al.*, 2017)	LPWAN technologies for IoT	Comparative review	Wide-area coverage, power consumption, data rate, scalability	General LPWAN comparison, not AMI-specific for TMCS
(Abdul & Wenqi, 2022)	Smart-grid communication technology evaluation	Fuzzy TOPSIS	Multi-criteria communication technology assessment	Not structured for TMCS and not validated against multiple dual-stage baselines
(Abdulsalam *et al.*, 2023)	Communication technologies for smart-grid applications	Overview + multicriteria analysis	Spectrum, data rate, coverage range	AMI case study exists, but not TMCS-specific and not based on the present sequential AHP-TOPSIS design
Present study	AMI communication technology selection for TMCS	Dual-stage AHP-TOPSIS with sensitivity and comparative validation	Data rate, battery lifespan, latency, communication range	Addresses TMCS-specific AMI selection and validates results using AHP-SAW and AHP-PROMETHEE

III. METHOD

This section outlines the research design for selecting the most appropriate communication technology for Truck Mobile Charging Stations (TMCS) using a dual-stage, structured multi-criteria decision-making approach.

A. Methodology Framework

The research framework for TMCS communication technology selection is shown in Figure 2. The framework is divided into four phases as follows:

- Phase-1: Criteria Identification and Candidate Selection The criteria for TMCS communication technology requirements are determined through expert opinion surveys and a literature review. Expert surveys are conducted through structured discussions to reach a consensus on the four most critical communication parameters: data rate, battery lifespan, latency, and communication range.

- Phase-2: Criteria Weighting Using AHP
  The Analytic Hierarchy Process (AHP) is applied to assign weights to the identified criteria. Experts perform pairwise comparisons to express their preferences and determine the relative importance of each parameter. The Consistency Ratio (CR) is calculated to ensure the reliability of the judgments, and the process is validated if CR < 0.1, indicating an acceptable level of consistency in the comparisons (Saaty, 1990).
- Phase-3: Alternative Evaluation Using TOPSIS
  The candidate communication technologies are evaluated using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. The AHP-derived weights are incorporated to compute the separation from the ideal and negative-ideal solutions. Based on these results, the alternatives are ranked to determine the most suitable communication technology for TMCS. A sensitivity analysis is performed to assess the robustness of the ranking results.
- Phase-4: Comparative Validation with Other Methods
  To validate the robustness of the proposed approach, a comparative analysis is conducted using multiple dual-stage MCDM methods. In addition to the AHP-TOPSIS model, two widely used dual-stage MCDM techniques—AHP-SAW and AHP-PROMETHEE are employed to rank the communication alternatives.

B. AHP-TOPSIS Method

In this study, a dual-stage MCDM is employed. In the first stage, AHP is applied to determine the weight of the MCS communication technology selection criteria. Subsequently, TOPSIS uses these weighted criteria to rank the alternative communication technologies based on their relative closeness to the ideal solution.

Within the AHP framework, pairwise comparisons are conducted among the criteria and alternatives to assess their relative importance, following Saaty's nine-point scale, as shown in Table 4.

The Eigenvector method derives the priority weights, while the Consistency Ratio (CR) evaluates reliability. A CR value below 0.10 indicates an acceptable level of consistency in the pairwise judgments, thereby validating the robustness of the derived weights.

Table 4. A Saaty’s Nine-Point Scale (Saaty, 1990)

Intensity of Importance	**Definition**
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very strong Importance
9	Extreme Importance
2, 3, 6, 8	Intermediate values

The AHP-TOPSIS approach consists of the following stages:

Step 1. Pairwise comparisons are utilised to construct the decision matrix, as illustrated below.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & c_{n3} & c_{nn} \end{bmatrix} \tag{1}$$

Where c_{ij} represent the i^{th}criterion importance value over the j^{th} criterion.

Step 2. Establish the decision matrix normalisation using (Eq. 2).

$$m_{ij} = \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}} \tag{2}$$

Step 3. Criteria weights are assigned, and the normalised decision matrix is computed using (Eq. 3) and (Eq. 4).

$$W = [w_i]_n \tag{3}$$

$$w_i = \sum_{j=1} \frac{m_{ij}}{n} \tag{4}$$

$$i = 1,2,3 \ldots n \text{ and } j = 1,2,3 \ldots n$$

Step 4. The maximum eigenvalue (λ_{max}) is calculated using the consistency vector (CV), which represents the consistency across criteria $[c_{vi}]_{1..n}$.

$$\lambda_{max} = \frac{\sum_{i=1}^{n} c_{vi}}{n} \tag{5}$$

Step 5. Obtain the consistency index (CI) and CR. If the CR is ≤ 0.10, the pairwise comparisons are considered consistent and acceptable. Otherwise, evaluators are advised to revise their judgments to improve consistency.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

$$CR = \frac{CI}{RI} \tag{7}$$

Step 5. Develop the normalised decision matrix (r_{ij}) and the weighted normalised matrix (C) using equations as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}} \tag{8}$$

$$v_{ij} = r_{ij}\, w_j \tag{9}$$

Where x_{ij} represents the value of the i^{th} alternative regarding to the j^{th} criterion.

Step 6. Calculate the positive ideal and negative-ideal worst solutions. The positive ideal solution (A^+) represent the maximum value of benefit criteria with minimum value of cost criteria, respectively the negative ideal solution (A^-) represent minimum value of benefit criteria and maximum value of cost criteria.

$$A^+ = \left\{ \left(\sum_{i}^{max} v_{ij} | j\varepsilon J \right), \left(\sum_{i}^{min} v_{ij} | j\varepsilon J' \right) | = 1,2,\dots,m \right\} = \{v_1^+, v_2^+, v_3^+, \dots, v_n^+\} \tag{10}$$

$$A^- = \left\{ \left(\sum_{i}^{min} v_{ij} | j\varepsilon J \right), \left(\sum_{i}^{max} v_{ij} | j\varepsilon J' \right) | = 1,2,\dots,m \right\} = \{v_1^-, v_2^-, v_3^-, \dots, v_n^-\} \tag{11}$$

where the beneficial and non-beneficial criteria, are respectively $J = (j = 1,2,\dots,n)/j$ and $J' = (j = 1,2,\dots,n)/j$.

Step 7. Derive the distance of each alternative from the positive and negative ideal solutions using (Eq. 12) and (Eq.13).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \tag{12}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{13}$$

Step 8. Asses the relative closeness to the ideal solution (C_i^*) to carry out the better alternative. The higher relative closeness indicates the most preferrable candidate.

$$C_i^* = \frac{S_i^-}{(S_i^+ + S_i^-)} \tag{14}$$

The computational complexity of the proposed dual-stage MCDM framework is approximately $O(n^2 + mn)$, where n denotes the number of criteria and $m$denotes the number of alternatives. In the first stage, AHP requires pairwise comparison and consistency analysis over the criteria set, leading to complexity of $O(n^2)$. In the second stage, TOPSIS requires normalisation, weighted matrix construction, ideal solution determination, and distance computation for all alternatives, resulting in complexity of $O(mn)$. Therefore, the total complexity remains efficient for practical decision-making problems involving a moderate number of criteria and alternatives.

Table 5. Criteria Pairwise Comparison

	Data rate	**Battery lifespan**	**Latency**	**Range**
Data rate	1	2.169	2.141	0.369
Battery lifespan	0.461	1	1.88	0.369
Latency	0.467	0.529	1	0.202
Range	2.173	2.713	4.957	1

IV. RESULT AND DISCUSSION

A. AHP to weight the Criteria

Table 5 summarises the opinions of six experts and provides an overview of the overall assessment. These experts, all with telecommunications backgrounds, contributed their judgments through pairwise comparisons of the selected criteria. The mean values derived from these comparisons reflect the relative importance or weights assigned to each criterion. The resulting priority rankings, calculated using the AHP, are presented in Table 6.

According to Table 6, communication range is considered the highest priority when selecting a telecommunication network for truck-based mobile EV charging, followed by data rate, battery lifespan, and latency. This is followed by data rate, which determines the speed at which data is transferred between the charging station, data centre, and EVs, thereby influencing the charging process. Battery lifespan and latency are also important factors to consider.

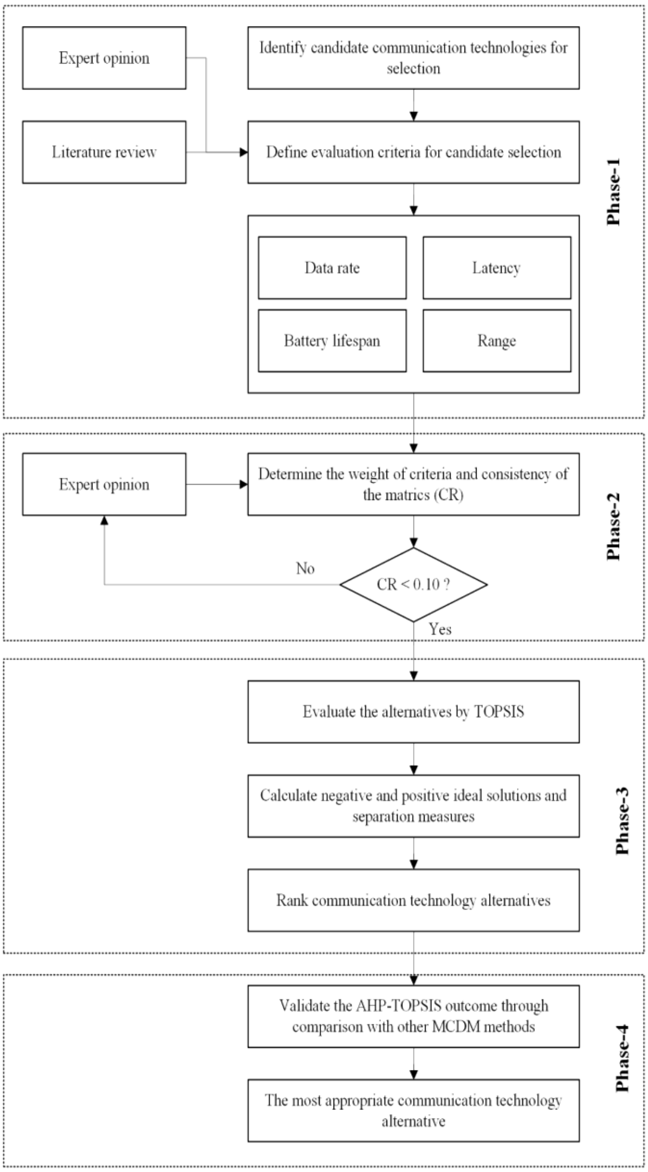


Figure 2. AMI Communication Technology Selection Framework

The system's adaptability, as indicated by the communication range in Table 6, enables the charging station to communicate effectively with the data centre and electric vehicles (EVs), regardless of location or charging activity within the designated area. This feature is essential for optimising the deployment and operation of TMCS in various locations and environments, including service stations and fleet operations.

With a broader communication range, TMCS can also serve more EVs without significant infrastructure upgrades or additional permitting processes. This is because a wider communication range allows the system to cover a larger area, thereby increasing the number of EVs it can serve simultaneously.

Table 6. Criteria Weight and Priority Rank

Criteria	**Weight**	**Priority Rank**
Data rate	0.239	2
Battery life span	0.157	3
Latency	0.097	4
Range	0.507	1
λ_{max}=4.162		
CR = 0.059		

B. *Ranking the Communication Alternatives using TOPSIS*

In this phase, the TOPSIS ranks the communication alternatives based on the weighted priority criteria listed in Table 6. This multi-criterion decision-making method facilitates a thorough and structured evaluation by comparing each alternative against the ideal and anti-ideal solutions, thereby enabling an objective ranking of the most suitable technologies (Vommi, 2017) .

The Euclidean distances of each alternative to the positive ideal solution (A^+) and the negative ideal solution (A^-) are computed across all criteria. These distances are then used to determine the relative closeness coefficient (C^*), which quantifies how close an alternative is to the ideal solution and how far it is from the worst-case scenario.

In the final step, (Eq. 13) is applied to compute the relative closeness value for each alternative. A higher relative closeness value indicates a superior alternative. As presented in Table 7, LTE-M (T2) exhibits the highest relative closeness score of 0.89, clearly emerging as the optimal option for AMI communication networks within the MCS framework. LTE-M performance across key criteria such as communication range, data rate, battery lifespan, and latency demonstrates LTE-M's capability to support real-time communication needs in various environments. In contrast, other technologies, such as LoRaWAN (T3) and NB-IoT (T1), show substantially lower closeness values, indicating weaker alignment with the ideal performance profile.

Table 7. Alternatives Relative Closeness

Alternatives	**Notation**	**A^+ (Best)**	**A^- (Worst)**	**Relative Closeness (C^*)**
NB-IoT	T1	0.23	0.01	0.05
LTE-M	T2	0.03	0.24	0.89
LoRaWAN	T3	0.24	0	0
Weightless	T4	0.23	0.03	0.12
Wi-SUN	T5	0.18	0.06	0.26

C. Sensitivity Analysis of Network Selection for Various Scenarios

A sensitivity analysis is conducted to evaluate the proposed model's performance under variations in the criteria weights. Since the criteria weights obtained from expert judgment may involve uncertainty, analysing how small changes in weights affect the final ranking is essential to ensure the reliability of the decision model.

This approach investigates how changes in the relative importance of each criterion affect the final ranking of communication technologies for TMCS. In each scenario, one criterion retains its original weight—determined through expert input—while the other three are assigned equal weights (Menon & Ravi, 2022). The weights of various scenarios in this study are depicted in Table 8 and detailed as follows:

- Derived: Weights are based on expert evaluations, as presented in Table 6.
- Scenario 1: Battery lifespan, latency, and communication range are equally weighted.
- Scenario 2: Data rate, latency and communication range have equal weight
- Scenario 3: Data rate, battery life span and communication range have equal weight
- Scenario 4: Data rate, battery life span, and latency have equal weight

Table 8. Criteria weights assigned to various scenarios

Criteria	**Derived**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Data rate	0.239	0.239	0.281	0.301	0.164
Battery lifespan	0.157	0.254	0.157	0.301	0.164
Latency	0.097	0.254	0.281	0.097	0.164
Range	0.507	0.254	0.281	0.301	0.507

By analysing the resulting rankings under each scenario, the study identifies which criteria most influence the selection process. If rankings remain unchanged, the model is considered stable. However, substantial variations in rankings suggest that specific criteria have a greater impact and should be examined more closely in future evaluations.

Table 9 presents the relative closeness values (C*) derived from multiple evaluation scenarios, while Table 10 summarises the corresponding rankings of communication technologies under each sensitivity scenario.

Table 9. Relative closeness values derived from various scenarios

Alternatives	**Notation**	**Relative Closeness Values (C^*)**				
		Derived	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
NB-IoT	T1	0.05	0.03	0.03	0.05	0.03
LTE-M	T2	0.89	0.88	0.93	0.84	0.88
LoraWAN	T3	0	0	0	0	0
Weightless	T4	0.12	0.13	0.08	0.17	0.13
Wi-SUN	T5	0.26	0.20	0.18	0.29	0.20

Table 10. Preferred communication technology ranking under various scenarios of sensitivity analysis

Rank	Derived	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	T2	T2	T2	T2	T2
2	T5	T5	T5	T5	T5
3	T4	T4	T4	T4	T4
4	T1	T1	T1	T1	T1
5	T3	T3	T3	T3	T3

The results demonstrate that LTE-M (T2) consistently achieves the highest closeness value across all scenarios, indicating its robustness and suitability for Truck Mobile Charging Station (TMCS) applications.

Specifically, LTE-M maintains the top rank in all five scenarios, with closeness values ranging from 0.84 to 0.93. This consistency highlights its strong performance regardless of changes in criterion weighting.

Wi-SUN (T5) generally ranks second under the Derived, Scenario 1, and Scenario 4 weight configurations. Meanwhile, Weightless (T4) and NB-IoT (T1) alternate between third and fourth place depending on the scenario. LoRa WAN (T3) remains the lowest-ranked option in all scenarios, with a relative closeness value of zero throughout. These results verify the robustness of the decision-making model and suggest that LTE-M is the most reliable and preferred communication technology for TMCS, regardless of shifts in criterion priorities.

D. Comparative Analysis of Dual Stage MCDM Methods

Table 11 presents a comparative evaluation of three dual-stage MCDM approaches, namely AHP-TOPSIS, AHP-SAW, and AHP-PROMETHEE.

Table 11. Comparison with other MCDM methods

Alternatives	AHP-TOPSIS		AHP-SAW		AHP-PROMETHEE	
	Score	Rank	Score	Rank	Score	Rank
NB-IoT	0.05	4	0.636	4	-6.093	4
LTE-M	0.89	1	0.9477	1	15.788	1
LoraWAN	0	5	0.624	5	-6.649	5
Weightless	0.12	3	0.688	3	-2.697	3
Wi-SUN	0.26	2	0.738	2	-0.349	2

The purpose of this comparison is to assess whether different ranking mechanisms produce consistent decision outcomes. The results show that LTE-M remains the top-ranked technology across all three methods, confirming the robustness of the proposed evaluation framework.

Table 11 shows consistency across all three methods, with LTE-M consistently ranking highest in each technique, confirming LTE-M as the most suitable communication technology for AMI within TMCS. Validates the dependability and accuracy of the AHP-TOPSIS method in capturing the key criteria for decision-making considerations.

Furthermore, Table 11 illustrates that the ranking order of the other alternatives remains consistent across the different methods, with Wi-SUN in second place, Weightless in third, NB-IoT in fourth, and LoRaWAN consistently ranked lowest. This alignment across various analytical approaches strengthens confidence in the evaluation results and the weighting of the selected criteria.

Although the scores vary due to methodological differences, the order of the alternatives remains unchanged, indicating that the AHP-TOPSIS model is compatible with other decision-making methods.

V. CONCLUSION

Reliable communication is a critical requirement for EV charging systems because it enables the accurate, timely transmission of metering and billing data from Truck Mobile Charging Stations (TMCS) to the utility data centre. This study proposed a dual-stage multi-criteria decision-making framework for selecting the most appropriate AMI communication technology for TMCS by sequentially integrating the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS).

The proposed framework evaluated four key communication criteria: data rate, battery lifespan, latency, and communication range. The results indicate that communication range is the most influential criterion (0.507), followed by data rate (0.239), battery lifespan (0.157), and latency (0.097). Among the evaluated LPWAN technologies, LTE-M achieved the highest closeness coefficient (0.89) and consistently ranked first across all sensitivity analysis scenarios. Comparative evaluation using FAHP-SAW and AHP-PROMETHEE further confirmed the stability of the ranking results.

These findings can be useful to EV charging operators when selecting the most reliable communication technology for data transmission from mobile charging stations to the data centre. The appropriate telecommunication technology will enhance communication reliability, ensure accurate billing, and improve overall system efficiency.

Future research can extend this work in several directions. First, additional criteria such as reliability, security, scalability, and deployment cost should be incorporated to provide a more comprehensive evaluation model. Second, the framework can be expanded to assess a broader set of communication technologies, including emerging cellular and non-terrestrial communication options. Third, uncertainty-aware approaches such as fuzzy AHP-TOPSIS or other advanced dual-stage MCDM models may be introduced to capture ambiguity in expert judgement. Finally, the proposed framework may be applied to other mobile charging configurations and emergency-energy scenarios, including TMCS deployment for disaster response and evacuation support.

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