Engineering Journal issn: 0125-8281

Article

Public Charging Station for Electric Vehicles in Thailand: A Comprehensive Practical Roaming Service Model

Waranthorn Tananuchittikul[1,a] **and Parames Chutima**[1,2,3,b,*]

1 Reginal Centre for Manufacturing Systems Engineering, Chulalongkorn University, Thailand
2 Industrial Engineering Department, Faculty of Engineering, Chulalongkorn University, Thailand
3 The Royal Society of Thailand, Thailand
E-mail: [a]waranthorn.tan@gmail.com, [b,*]parames.c@chula.ac.th (Corresponding author)

Abstract. The electric vehicle (EV) charging infrastructure in Thailand is currently encountering several challenges, especially in facilitating customer journeys and streaming customers across public charging stations. Given the charging service is continually growing among the shortages of EV charging stations, customers are forced to navigate through several mobile applications (apps) for service accessibility due to those charging stations being operated fragmentedly. Albeit notional entities endeavour to implement EV roaming, to integrate the fragmented charging station across the country, they face several problems on unfulfillable of the current adopted technology. This situation reflects the customer satisfaction and behavioural trend, surfacing dissatisfaction in several customer experience areas, particularly the non-extensiveness of the reservation system. This research addresses these gaps by proposing a tailored-made roaming service model that not only aligns with the Open Charge Point Interface (OCPI) framework, which is currently adopted in Thailand but also incorporates specific adjustments for the market needs. Stakeholder acceptance of the model is twofold: operators' acceptance is measured by its capacity to deliver Business, Operational, and Technical Excellence, while end-user acceptance hinges on a seamless charging experience.the target is to establish a new conceptual service model that bridges the gaps of unfulfillments and enhances the EV charging journey on customer satisfaction, technology acceptance, and operational effectiveness. In addition, key practical solutions are offered for Charge Point Operators (CPOs) and E-Mobility Service Providers (EMSPs) to deliver a seamless and user-centric charging experience.

Keywords: Electric vehicles, EV charging infrastructure, EV reservation, EV roaming, open charge point interface, charge point operator, e-mobility service provider.

ENGINEERING JOURNAL Volume 29 Issue 8
Received 16 February 2025
Accepted 21 July 2025
Published 31 August 2025
Online at https://engj.org/
DOI:10.4186/ej.2025.29.8.37

1. Introduction

Electric vehicles (EVs) have recently proliferated in Thailand and have been adopted exponentially since 2022, at the rate of 241% approximately, which is the highest growth in Southeast Asia [1]. These adoption phenomena are not only foreseeable in the capital city but also outskirts and upcountry. The government policy to increase EV supply in Thailand attracts Chinese and European automotive Original Equipment Manufacturers (OEMs) to establish factories and manufacture EVs in Thailand [2]. Along with the EV supply that is expected to surge sharply in the coming year, the demand for EV charging services in the private sector (e.g., home-used, condos), public sector (e.g., commercial stations, department stores, offices, community malls), and government sector are also expanding. However, the number of today's charging stations seems not sufficient to serve all EV charging demands in the coming years. This could be observed when delving down into the statistics given by [3], the average ratio of charge points (CP) to serve one EV is 1:10, computed with the forecasted number of BEVs in Thailand as of 2023 as, 150,571 EVs. Hence, at least 15,200 charge points are needed to serve the total EV charging demand. Compared with the forecasted situation of Thailand, having 8,300 EV charge points across the sectors, still lacks the forecasted number by 6,900 CPs or 45.4%. The CPs are mostly located in the high demand areas such as capital cities or tourist attraction cities and less in the upcountry areas. Indeed, the accessibilities of these charge points are deemed inconvenient as each charge point belongs to distinct charge point operators and is being operated fragmentedly. As a result, EV drivers in Thailand must agonisingly utilise the different EV charging apps to access those CPs.

Since 2022, the Electric Vehicle Association of Thailand (EVAT) has endeavoured to solve the customer's burden by controlling integration responsibilities for each Charge Point Operator (CPO), standardising the Open Charge Point Interface (OCPI) integration model, and enforcing the roaming system to all CPOs in Thailand [4]. However, there was no consensus on the integration components and definite scope. Therefore, no significant move has been executed yet. The obstacles in establishing the roaming service could be perceived on both customer-related factors and service providers' factors per se, including 1) no official collaboration and in-depth research on charging behaviour resulting in no consensus on the expected charging journey among the party, and 2) lack of comprehensive integration model, and CPOs' conflict of interest. There are a few international associations that designed an integration-roaming framework to facilitate cross-network access which could partially be adapted to the Thailand market, e.g., OCHP, OICP, eMIP, and OCPI. However, those existing roaming services fall short of comprehensiveness, not to mention monetary system integration, tax issuance, booking system, and parking bay integrated system, failing to address the needs and patterns of Thai charging behaviours and CPOs' needs. The customer behaviour analysis of SHARGE in 2023 [5] found that Thai EV drivers utilised the reservation system according to the type of destination they planned to use the charging service, such as department stores, community malls, and condos; yet, not required for the rest others. This could be evidence that the mentioned roaming system is not comprehensively fit and needs additional development to serve the Thai industry.

As the problems persist, Thai EV drivers not only experience a complicated charging experience but are also unable to fully access the available CPs since they are not adopting all EV charging apps. Conceptually, if 31.3% of users adopt only 1-2 apps of the largest CPOs according to SHARGE's research, they might be able to only access 1,943 CPs or 41.2% of the total EV charging stations, accounting for only a 1:30 ratio of CPs per EV, which is lesser than the recommendation of IEA [3] by far. This situation may lead to inconveniences, uneven access to charging stations, and potential market imbalances, with some applications dominating. In addition, this could result in charging point congestion, reduced competition, and barriers to wider electric vehicle adoption due to the feeling of uncertainty of chargers' accessibility accompanied by range anxiety [6]. The ramifications might also be treated as obstacles to achieving the national goal of having 725,000 EVs and 30% of car manufacturing as EVs by 2030 [2].

Recognising these challenges, this research targets a comprehensive exploration of the EV charging landscape in Thailand, guided by the principles of service design theory. By delving into both the perspectives of EV owners and service providers, this research aims to unearth the underlying issues and needs, elucidating the core issues and unmet needs within the existing solutions. The goal is to propose a suitable and customer-centric integrated roaming service model, which could be another alternative option to revolutionize the way EV charging services are delivered in Thailand. This model seeks to enhance the accessibility, efficiency, and convenience of EV drivers using charging services, but also interoperability benefits of the service providers, potentially serving as a blueprint for sustainable growth in the Thai EV market.

This research aims to study several critical factors of feasibility study, including the current state of EV charging infrastructure in Thailand, the challenges of EV users and service providers, and the principles of service design theory that potentially bridge the existing gaps. By examining these facets, this research endeavours to propose an alternative solution for the challenges and then validate the adoption tendency by measuring the intention to adopt TAM. This research endeavours to provide valuable insights and actionable recommendations for a more cohesive and user-centric ecosystem that fosters the growth of electric mobility in the nation.

The following is the structure of the article's remaining sections. In Section 2, a review of the literature is conducted. Section 3 offers a method to address the challenges mentioned previously. Section 4 presents the findings, whereas Section 5 contains the concluding remarks and their implications.

2. Literature Review

Electric Mobility topics have been substantially studied since the mass adoption of EVs, including both supply - EV adoption and charging stations, and demand - the reasons for adoption and EV charging behaviour [7]. According to the scope, this research only focuses on charging behaviour and the need for charging infrastructure in public spaces which potentially be beneficial in conceptualizing users' needs.

2.1. Charging Infrastructure

Accessibility of EV charging stations is one of the significant key factors of EV adoption as well as the level of range anxiety, which is partially rooted in the number of established EV charging stations. Fröde et al. [8] projected that the proportion of EV charging stations in the US will move from residential areas to more diversified public spaces in 2023 and the cumulative needed to serve the charging demand is 1.2 million chargers, requiring at least $38 billion for public station setup. In Thailand, SHARGE [5] projected that the demand for charging infrastructure needed in 2025 is 568,000 EV charging outlets, yet still lack 68.3% of the projected establishment.

2.2. Charge Point Operator Challenges

The key profitability of EV charger establishment is generating revenue depends on two factors, i.e., 1) utilization and 2) price per kWh [8]. To strategically set the pricing to reach the expected utilization, it is important to understand customer behaviour and preferences in using public charging services. Charging fares and convenience are the two main drivers for customers to use public charging stations. The higher convenience or the lower cost would help increase charger utilization [9]. This also confirms the findings of Ma and Yang [10] that customer satisfaction with charging service was rooted in cost, facilities, availabilities, and service experience. Moreover, a positive result was also proposed by Pagani et al. [11], who found that EV drivers tended to refer to two factors, i.e., price and comfort in decision-making. Yet, the cost factor outweighed the convenience factors. The challenge of CPOs, therefore, lay in the revenue they could generate with the rise of competition, which potentially lowered the selling price, to compete over the higher cost of land use [12].

2.3. User Preference

The preferences of EV drivers were also examined and found that EV drivers valued interoperability between charging services as it enhanced their convenience in accessing the charging facilities [9]. This also aligned with the findings in [12], which interoperability was one key in decreasing range anxiety as the customer could access the charging facilities more easily. Moreover, another reported challenge of EV users was the limited accessibility of EV charging information, by having an integrated network solution. EV drivers could be more confident in using EVs along with a higher level of satisfaction and better user experience [14]. Moreover, collaboration and partnership were also highlighted, as they could yield a competitive advantage to CPOs [12]. They also found that interoperability service might yield not only higher utilisation but also collaboratively generate horizontal reserve stream among parties as they leveraged the same physical and digital infrastructure. However, the need for roaming varied across the implemented context including charger density, market competition, and regulation.

The charging patterns of users were categorised into three patterns 1) fuel-filling pattern – waiting for the battery to lower users' subjective threshold (20 – 30% SoC [15], 2) planned charging – charging plan according to the needs of battery consumption, such as going for a trip, and 3) event-triggered – charging whenever they had opportunities [16]. [17] proposed a conceptual decision-making model of charging. Furthermore, the concern of time uncertainty in charging and driving EVs was found as one of the major concerns of EV drivers, that drivers tended to change their charging destinations if there was a long waiting time before they could start charging [18].

2.4. Interoperability Model and Infrastructure

2.4.1. Reservation system

The concept of minimising customer waiting time in the EV industry has been extensively examined and proven that it could yield benefits to the customer and load providers. Along with [19], a centralised reservation system aimed to be an alternative way to minimize waiting time and charging hotspots before a customer could start charging. The model utilised a global aggregator as a control system which could also connect with another third party in the peer-to-peer model, suggesting the most appropriate stations available. The reservation system not only lowered the waiting time but also increased utilisation of the EV charging stations.

[20] addressed the problematic issue of the user's waiting time and proposed an alternative queuing system for EV drivers to choose whether to wait in the queue or change their destination. They claimed that the model could not only save and manage the charging loads but also minimise users' waiting time. However, there was no explicit result explaining to what extent the users saved their time, as well as the need to wait in queue. A model related to the open charge point protocol (OCPP) was proposed to facilitate the reservation model using "Reserve command" to trigger the EV chargers from an application service (E-mobility service provider - EMSP) [21]. The proposed solution allowed users to make a

reservation immediately at the moment they requested, supported by the EMSP system to receive and forward communications between the charge points. After implementing the proposed solution, the planned reservation could help EV drivers achieve a better driving experience, i.e., the higher the demand the more benefits for the drivers.

At the end of the open charge point protocol (OCPP), the limitation of “reserve now” was examined by [22]. An alternative way, yet a central reservation system to cope with the uncertainty of charger availability, was proposed. This model allowed users to make charging reservations ahead of schedule, instead of the typical reserving a charging slot by now. The benefits of this model aligned with the previous research, while customers could experience a better charging experience and increased customer satisfaction. In addition, the energy manager could also distribute their resources properly.

2.4.2. Roaming system

Kam and Bekkers [23] conducted extensive research on EV roaming infrastructure since 2020 as an ability that enables an EV driver who had signed up with one E-Mobility Service Provider (EMSP) to trigger a charging activity with an EV charger operated by the different Charge Point Operator (CPO) whom in contract with another. In other words, a system that allowed a user to initiate activities against EV chargers of different service providers. For example, a user uses an app belonging to provider A to start charging at the EV station of provider B. The benefits of EV roaming have been claimed by many practitioners both customers’ benefits and providers, such as a more seamless charging experience, higher accessibility for EV charging stations, increased EV charger utilization, and reduced range anxiety [24].

Many roaming terminologies were available for implementers to adopt. Those protocols were compared and chosen as the most publicly accepted around the EU including, OCHP, OICP, eMIP, and OCPI [25]. Seven design components that could be referred to as a baseline of the system design were suggested, including 1) comprehensive core functionalities, 2) Architectural openness, 3) use of options, 4) ease of scalability, 5) Open standard, 6) Business wise compliant, and 7) ability to control over quality.

2.4.3. OCPI standard

OCPI is a standardized roaming framework, that aims to accelerate EV adoptions and improve EV charging service experiences (EV foundation). The core functionalities support 1) roaming on the hub and peer-to-peer basis, 2) authorization, 3) handling tariff, 4) charging details transferring, 5) charge point information sharing with real-time status, 6) Session summary, 7) smart charging, and 8) reserve now function [26]. In other words, the OCPI modules consist of a token module, location module, tariff module, session module, command module, and charging detail record module (CDR). There are three main entities named EMSP (application service), CPO charge point operator, which is connected to the HUB.

Although the OCPI offers a wide range of functionalities, it might not be a total solution for EV charging service since it might not be fully compatible with some specific behaviours and business obligations. For example, 1) making a scheduled reservation instead of now could not be executed through OCPI, 2) the tax issuance responsibility and tax invoice are not comprehensively managed, since it might not be able to issue a tax invoice albeit the total price including tax has been taken into account in the tariff module since the lack of customer data, 3) commercialization of roaming service haven’t been justified explicitly in terms of roaming fee in tariff module, 4) the roaming need a reconciliation system behind the scene to manage all cross-platform transaction.

To sum up, previous research has explored various aspects related to EV charging. Yet, an integrated approach encompassing all relevant dimensions remains limited. For instance, some studies empirically examined and summarised customer charging patterns, while others have analysed customer preferences regarding the design of the charging journey. Additional studies addressed reservation systems, roaming, and proposed frameworks for EV charging station operations. To emphasise the research gap, this study aims to synthesise these insights from both the literature and practical market findings, focusing on charging patterns, user preferences within the Thai EV charging market, and aspects of charging applications, including reservation and interoperability models and service provider obligations. Ultimately, this research intends to deliver a comprehensive contribution to both academic literature and practical applications, benefiting the broader community.

2.5. Acceptance Model

2.5.1. FAHP

The fuzzy analytical hierarchy process (FAHP) applications have proven the legitimacy of the use cases which align with this research topic area of service model selection. Therefore, it is deemed a suitable instrument in the selection of this research. Given that different FAHP models could yield different advantages [55][58], [27] compared five renowned FAHP methods including [28] then concluded that they could yield the same results, yet in different FAHP weights. The extended analysis model was digested and simplified by [29].

The model structure, formulas, and calculation steps could be derived as follows. The structure of the FAHP is illustrated in Fig. 1, comprising two primary levels, i.e., main criteria, and sub-attributes. The main criteria represent the overarching evaluative dimensions against which each alternative is assessed. The sub-attributes delineate the specific characteristics underlying each criterion. Alternatives, positioned below these levels, signify the options or elements that are evaluated concerning the established criteria.

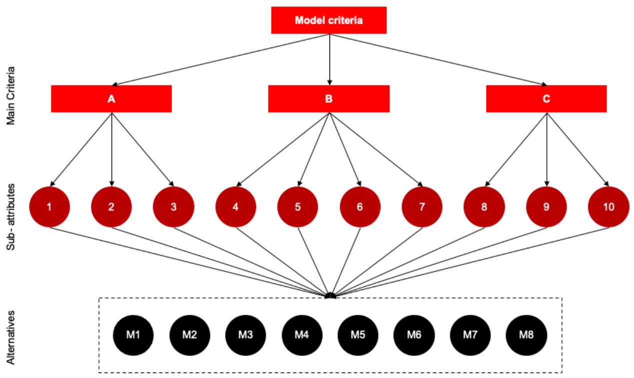

Fig. 1. Structure of the FAHP model

The FAHP method requires experts' judgment on comparing the pairwise. The scoring of FAHP comprises two types, i.e., 1) normal score, and 2) reciprocal score. Experts are required to justify to what level A could contribute to the measurement target when compared with B, and the scoring of the fuzzy matrix is applied according to those judgments [30]. The survey questions of this method are based on comparing each pair in the same measurement areas. These comparisons create fuzzy numbers which are utilised in the later calculation steps. In this research, the fuzzy handling mechanism was adopted from Chang's triangular fuzzy number [28]; meanwhile, the calculation equation was adopted from [30].

2.5.2. Technology Acceptance Model

The Technology Acceptance Model (TAM) was introduced as a model that aims to help designers and implementors examine their proposals by providing insights into users' perspectives on the design or implementation of an information technology (IT) system [31]. The model aims to answer the hypothesis of whether or not the users would adopt the IT system model – actual adoption through behavioural intention to use (BI) by asking users' opinions using interviewing methods or having interactions with the focus sampling [32]. In doing so, two main factors are measured, namely perceived usefulness – how the user perceives if the IS increases their performance (PU) and perceived Ease of Use – how much effort the user thinks that they devoted (PEOU), where PEOU and PU are influenced by features, and PEOU affects PU but not in vice versa. Indeed, this model was the integrated result of many studies including the TRA model which illustrated the impact of beliefs, attitudes, and satisfaction [32].

2.5.3. Structural Equation Modelling (SEM)

SEM is adopted as an instrument in data analysis in this research. The computation of SEM is done through IBM AMOS 28 and IBM SPSS 29 as follows:

- The first step is descriptive analysis where data set suitability is examined [56]. This step objective is to validate on suitability of the data set that will be utilised in SEM [33]. A bivariate correlation matrix, multicollinearity check, and normality test with Skewness and Kurtosis values are the main instruments for this step. This step ensures the normality distribution of the data form and is free from multicollinearity issues.
- The second step is a data set reliability check. This stage focuses on validating the reliability of the data set before devoting effort to the next step. If the data set possesses poor reliability, those data sets might not be suitable for SEM [34]. Cronbach's alpha is used as the main instrument, accompanied by Corrected Item-Total Correlation, measuring the data set overall reliability and internal reliability.
- The third step is to validate constructs or scales. These steps aim to validate how well the construct measures according to its intention measuring through loadings [35]. This stage includes Exploratory Factor Analysis (EFA) applied for scale and construct development construct validation, and Confirmatory Factor analysis (CFA) for validating the established relations between observed variables and their underlying latent constructs.
- The fourth step concerns the model formulation according to the measuring intention, in this research, according to TAM theory [32]. The SEM model is validated through model fit indicated as the same as the validating model in the CFA section. However, the significant level (p-value) must be higher than 0.05 for acceptance criteria [36]. If the model does not fit well the measurement and interpreted relation might not be accurate [37]. Therefore, the model specification is implemented namely "Modification Indices (MI)". MI is a statistical method that improves the model by adding more covariance among variables yet needs to be added into the same construct [38]. After the correction, the model is re-validated through model fit to ensure validity. If the model positively fits the measurement indices, the model is ready to be interpreted in the next stage.
- The final step is to examine the correlation and relationship between the validated SEM model. It is conducted by the path analysis technique [33]. Utilising the path analysis, we could objectively validate the research hypothesis if the developed model is acceptable.

3. Research Methodology

This research was structured according to the design thinking ideology [39][57] applied to the double Dimond framework [40]. Fig. 2 illustrates this research adaptation of this ideology comprising four key phases, i.e., 1) Discovery phase (Problem identifying) – gathering insights through market research, surveys, and social listening to evaluate current service performance, 2) Definition phase (pain point consolidation) – identifying and analysing gaps between existing practices and user expectations, while pinpointing root causes by integrating findings with the SERVQUAL and Ishikawa frameworks, 3) Alternatives development phase (solution generating) – generating and refining alternative solutions based on insights from phase two, with potential service models formulated through focus group discussions for validation in the subsequent phase, and 4) Solution consolidation phase (Deliver phase) – validating acceptance criteria by employing the FAHP method, enabling service provider representatives to prioritize preferred models, which are subsequently assessed for customer acceptance using the TAM framework.

Figure 3 outlines each phase of the design thinking methodology, detailing the specific actions taken within each stage with the expected outcome of each stage, e.g., market research, gap analysis, and model formulation, and links these actions to the theoretical frameworks supporting them, e.g., SERVQUAL, Ishikawa, FAHP, and TAM. This structured overview emphasises the alignment of research practices with established theories, providing a comprehensive framework for both practical implementation and academic validation.

3.1. Identifying the Source of Information

This study employed a mixed-methods approach, collecting both primary data such as through survey interviews, and secondary data, gathered via social listening, market research, and company reports. The sample size was calculated following the methodology proposed by [41]. The research focused on two primary objectives, i.e., 1) evaluating current market practices, and 2) assessing the actual performance of these practices. This phase involved market research, customer satisfaction research, and quantitative research. To achieve these objectives, the study collected public information on the customer journey and surveys EV drivers in Thailand who experienced EV roaming. Additionally, data from operators were collected to analyse the real-world use of specific functionalities.

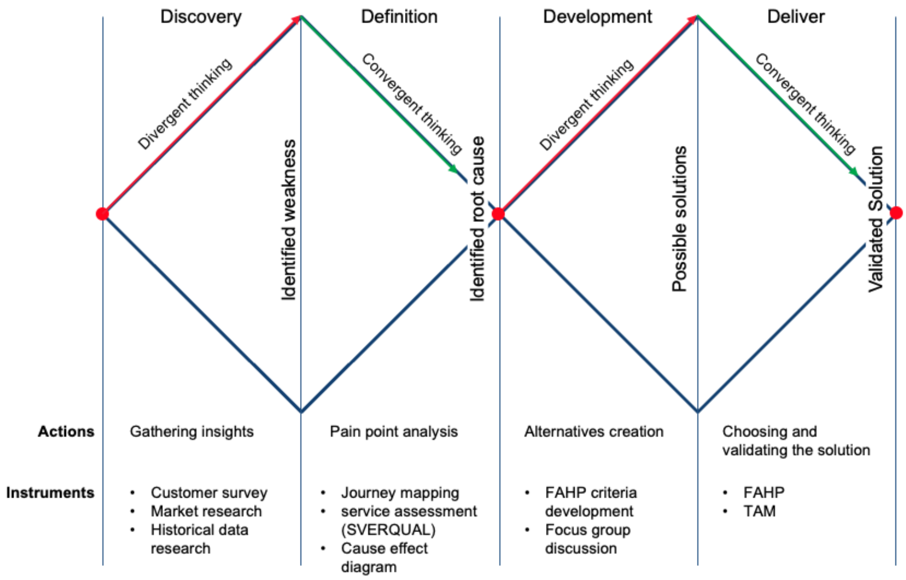

Fig. 2. Double diamond framework

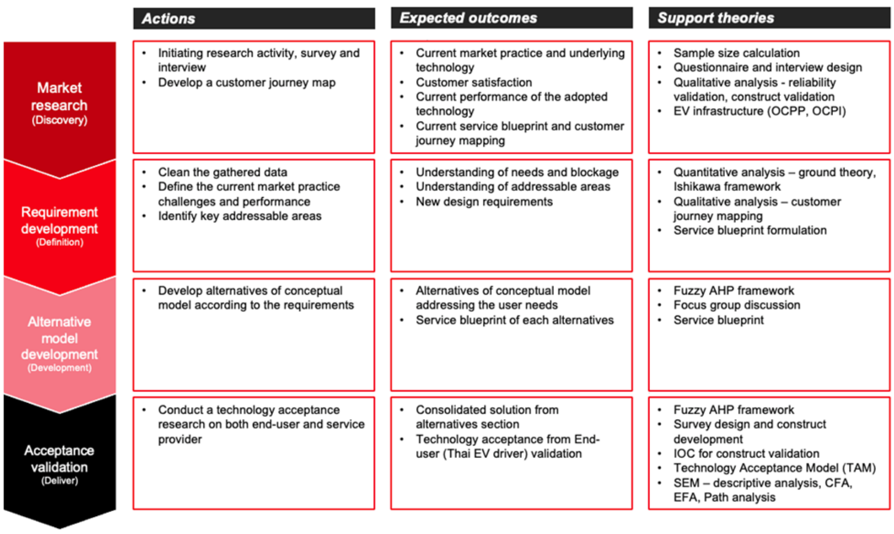

Fig. 3. Design thinking framework

3.2. Conducting Data Collection

The primary data-gathering processes were structured and performed according to the tailored design method [42], which focused on specificness, interaction framework, and social exchange. Given the emotions of the customer were a crucial part of understanding their pain points, the Linkert scale was adopted in translating qualitative into quantitative data which was utilised in the customer mapping journey in the further step [43]. The survey questions were validated by experts through IOC instruments. In doing so, there were data-related problems expected as 1) inaccurate data, 2) irrelevant data, and 3) bias inputs which needed to be cleaned. Strictly, this research declared the objective of the research and the PIL leaflet and allowed respondents to consent or reject the survey before starting.

3.3. Data Analysis

The raw data consists of both quantitative data and qualitative data; therefore, this paper adopted qualitative and quantitative frameworks to analyse those data [44]. This research started with quantitative analyses using SPSS to validate the reliability of the data gathered and then analysis through a grounded theory mindset [45]. The insights from quantitative into customer journey mapping were visualised to summarise customer satisfaction along the journey [46]. This customer journey map included the quantitative scoring of each touch point and Qualitative/ Narratives as emotionally attached.

After gaining insights regarding the current situation and visualising it more clearly, the next step was to input customer-envisioned opinions into the deriving processes to find the gap between the existing journey and a better solution. This gap was used to establish initiative ideas in the designing phase [47]. This research adopted the SERVQUAL framework [48] in analysing the current insight to identify the weaknesses gap of the current system performance. Thereafter, the Ishikawa (cause-effect diagram) framework was employed to analyse the potential gap root cause.

3.4. Alternatives Formulation

After consolidating the user's requirements from end-users, the researcher then connected with experts and some service providers to start designing the new system using the gathered insights. FAHP was adopted as a main tool for service provider acceptance validation, therefore the service alternatives were formed in branches of service models. After the alternative generations, we adopted a service blueprint to summarise and visualise the interaction connections [49], deriving 1) physical artefacts 2) customer actions, 3) visible actions, 4) invisible actions, and 5) support processes while taking the five principles of service design thinking [50] as a prime lens while conceptualizing the new service.

3.5. Model Acceptance Testing and Validation

This stage concentrated on validating the model to evaluate both service provider and customer acceptance. The validation process was divided into two distinct sections: 1) Service Provider Acceptance Testing, and 2) End-User Acceptance Testing. This study also employed the FAHP as the primary methodology for validating service provider acceptance. Initially, a focus group discussion was conducted to determine the key attributes preferred by service providers for assessing the service model. Subsequently, another focus group, consisting of the same participants, was held on a different day to facilitate pairwise comparisons of the identified attributes, enabling judgments on their relative importance according to the FAHP methodology.

The TAM framework [31] was adopted as a foundational approach to analyse customer acceptance of the proposed service model, focusing on the relationships among Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Behavioural Intention to Use (BI). A new set of survey-interview questions was designed and validated using the Item-Objective Congruence (IOC) method, ensuring alignment with TAM variables to accurately capture user perceptions of the model. Following data collection, the study employsed SEM for quantitative analysis to examine correlations between TAM variables; thereby, validating the interrelationships among parameters and assessing the degree of influence each parameter exerts on adoption likelihood within the TAM framework.

4. Results

This section presents the results derived from the comprehensive research methodologies outlined in the previous chapters. Drawing upon a systematic approach, which began with market review thereafter rigorous user research, and proceeded through requirement development, service model creation, and feasibility testing, the key findings that emerged from these processes are synthesized. The data were thoroughly analysed using qualitative and quantitative methods to address the primary research questions and hypotheses. In addition, we carefully examined how each research phase from identifying user needs to evaluating service models played a role in achieving the study's overall goals.

4.1. Customer Journey Overview

The Charge Point Operators (CPOs) in Thailand comprise 15 operators, each utilising their proprietary charging applications. Of these, eight operators provide a standardised charging process that encompasses seven key steps, i.e., 1) searching for charging stations, 2) making a reservation, 3) accessing the charging station and initiating a charging session, 4) monitoring the charging status, 5) terminating the charging session, 6) reviewing the invoice and completing payment, and 7) optionally issuing a tax invoice. The other operators have not yet implemented the reservation feature (Step 2). The overview of the customer journey can be explained as follows.

The first journey is searching for a charging station journey. This journey enables users to search and browse through the existing location in the charging network and inform the status of the charging stations. The journey functionalities include 1) Searching for location through map browsing, 2) searching by name through the search function, 3) navigating within all or being redirected to a third-party app, and 4) showing chargers' information such as availability and readiness. These features are embedded in most charging apps including Sharge, Recharge, EA Anywhere, EV Station Pluz, and Elex.

The second journey is making a reservation journey. This action allows users to inspect the availability and make a reservation to pre-book the charging slot. There are three sub-actions through this journey including 1) selecting a charge point, 2) selecting charging duration and slot, and 3) confirming the reservation detail. There are 6 out of 15 CPOs enable these features, accounting for 63.3% of the total charge points. This touchpoint could be questioned on how useful the reservation serves users and if it is necessary to be included in the new EV roaming service model.

The third touchpoint is initiating a charging session. The objective is to ensure that users have arrived at the station and have the intention to start a charging session. There could be alternative approaches including QR code scanning or swiping to start charging. Thereafter the app sends a command to the specified charger to start charging. Some apps also have additional pages to let the user acknowledge the action by showing them the loading page.

The fourth journey is to secure a payment. Each app might offer different payment methods including credit card, debit card, wallet, and QR code scanning. In this step, users are allowed to inspect the correctness of the invoice and apply any privilege they are entitled to. Thereafter, the users will click a call-to-action button such as "Pay" to secure the payment, and then the application will show the charging summary and receipt.

The last journey is to request for Tax invoice. This step's objective is to allow users to request tax invoices. Some apps include this functionality as per users' request and others automatically generate the tax invoice to the customer's preferred channel, e.g. email or downloadable site.

4.2. Underlying Roaming Technology

The Electric Vehicle Association of Thailand (EVAT) gathered EV charging station operators in Thailand recently, consisting of 21 operators, to sign the Memorandum of Understanding (MoU) regarding continuing EV roaming collaboration [51]. This event proved the intention of roaming collaboration in Thailand. Concerning the integration, the participating companies agreed to continue the EV roaming development. In addition, they agreed to adopt OCPI 2.2.1 as a main medium; however, there was no additional module or actual charger availability sync-up system. This confirms that the consortium solely utilises the EV roaming – OCPI module as a main integration technology.

4.3. Customer Survey

The focus of this section is to unearth insights from the current market practice and to understand more about system performance and the challenges that users are currently facing. A survey was systematically conducted. It utilises quantitative measurements to gather insights from statistical and emotional perspectives. 33 questions were asked divided into two main sections: 1) Persona Screening, and 2) Customer Journey Measurement. The questions are designed to capture insights into the customer journey of EV charging services, focusing on seven sub-touchpoints: 1) Searching and Planning the Charging Journey, 2) Reservation Process, 3) Initiating the Charging Session, 4) Monitoring Charging Information, 5) Ending the Charging Session, and 6) Securing Payment and 7) Issuing a Tax Invoice.

The survey was conducted in collaboration with a private company, one of the top EV charging service providers in Thailand which is a part of the Electric Vehicle Association of Thailand (EVAT). The survey team consisted of nine members, including one business development manager, five mid-level business developers, two service designers, and the researcher. During the survey, the survey objective was elaborated before conducting it along with the consent letter. The survey was carried out over 67 days at actual charging stations of the five most frequently mentioned charging brands and the EV roaming-operated stations. After excluding outliers, unintentionally completed surveys, and persona screening of having experience in using EV roaming service, only 261 out of 473 valid responses were collected. These 261 responses were processed 90% confidence level approximately, with a 5% margin error. Therefore, this dataset was trustworthy enough for further analysis.

The Item-Objective Congruence (IOC) technique was used as the principal framework for validating the survey constructs through three experts, comprising both academic and industry professionals. The results of the construct validation were favourable, with each item's IOC score exceeding the established threshold of 0.5, and an overall average score of 0.95, significantly surpassing the recommended benchmark of 0.5 [52]. These findings indicated that the survey items exhibited a high degree of reliability and were appropriate for data collection.

4.4. Survey Result Reliability Assessment

The study employed quantitative measures, including Cronbach's alpha and Corrected Item-Total Correlation to assess the internal consistency and reliability of the constructs. The primary measurement tool was a customer journey assessment, which was categorised into seven subdimensions (Table 1). Specifically, four items evaluate customer satisfaction with the "Searching and Planning the Charging Journey" phase, four items assess the "Reservation Process," and four items measure satisfaction with the "Initiating the Charging Session." Additionally, three items address satisfaction with "Monitoring Charging Information," three items evaluate the "Ending the Charging Session" phase, four items assess "Securing Payment," and four items measure satisfaction with the "Issuing a Tax Invoice" process. The reliability of the 26 measurement items, evaluated with data from 261 respondents, was assessed using Cronbach's Alpha. All constructs exhibited satisfactory reliability. Cronbach's Alpha values for individual-based measurements and domain-based measurements fell in the acceptable range, indicating strong internal consistency across the survey constructs.

Table 1. Internal consistency and reliability assessments.

Domain	item	Corrected item - total correlation (> 0.3)	Cronbach's alpha	Group Cronbach's alpha
Searching and Planning the Charging Journey	1	0.562	0.766	0.795
	2	0.642	0.737	
	3	0.673	0.713	
	4	0.578	0.759	
Reservation Process	5	0.634	0.763	0.811
	6	0.62	0.769	
	7	0.664	0.746	
	8	0.605	0.774	
Initiating the Charging Session	9	0.576	0.768	0.8
	10	0.613	0.752	
	11	0.651	0.73	
	12	0.62	0.746	
Monitoring Charging Information	13	0.632	0.754	0.805
	14	0.681	0.703	
	15	0.645	0.742	
Ending a Charging Session	16	0.675	0.767	0.824
	17	0.701	0.739	
	18	0.672	0.765	
Securing Payment	19	0.628	0.762	0.81
	20	0.629	0.761	
	21	0.654	0.755	
	22	0.611	0.77	
Issuing a Tax Invoice	23	0.775	0.872	0.899
	24	0.798	0.871	
	25	0.788	0.866	
	26	0.773	0.871	

4.5. Descriptive Analysis

The summary of general information respondents was summarised as follows. The dominant age group was 31-40 years old (37.2%), followed by 20-30 years old (24.5%), 41 - 50 years old (22.6%), 51-60 years (15.3%), and over 60 years (0.4%). Males accounted for 51.3% of the gender composition, while Females made up 48.7. Regarding the Education spectrum, 64.0% hold a bachelor's degree, 17.6% a master's degree, 13.8% a high school graduate, and 4.6% a doctorate. Most respondents possessed 6 months - 1 year of EV driving experience (44.8%), followed by more than 1 year - 3 years (34.1%), less than 6 months (14.9%), and over 3 years (6.1%). Charging frequency was highest at 1-2 times per week at 45.6%, followed by 3-4 times at 36.0%, 5 - 6 times at 16.5% and the least at 7 times at 1.9%. The number of application usages per user was dominated by a group of people who use 3 – 5 applications for their daily life at 47.5%, followed by 6–7 applications for 36.4%, 1-2 applications at 12.6%, and more than 7 applications for 3.4%.

4.6. Customer Journey Mapping

This section summarises the survey results, focusing on the customer journey assessment. The objective was to measure how well the current practice serves users based on 7 main areas. The results (Fig. 4) exhibited dissatisfaction including Searching and planning the charging journey at 2.87, Issuing a tax invoice at 2.85, and reservation journey at least at 2.61. The analysis of the results was elaborated as follows.

According to the survey, EV drivers rated their experience with Searching and Planning the charging journey below their expectations. The most significant dissatisfaction emerged from their interaction with the displayed charging stations. These findings suggested that while users could find charging stations, the information provided was often inaccurate and the inability to effectively interact with the stations further diminished their overall experience and expectations.

Regarding the reservation process, users reported a significant discrepancy between their reservations and the actual availability of charging stations. This discrepancy could be interpreted as a lack of synchronisation or accuracy between the information provided by the charging application and the real-time availability of the charging stations. Consequently, when users arrived at the stations, the chargers were often unavailable despite being reserved, further contributing to their dissatisfaction.

The third underperformed area was the issuing of tax invoices. This was due to the users could not receive the tax invoice. This section could be conceptualised as users might not receive the tax invoice or seem to be hard when requesting a tax invoice. Thereafter if they issued the request, the Tax invoice got issued in normal standard.

4.7. New Service Model Requirements

4.7.1. SERVQUAL analysis

SERVQUAL and Ishikawa (Cause-Effect diagram) were applied in this section. The objective was to highlight the possible root cause of each issue and utilise those insights in developing a new conceptual service model. From the customer journey mapping, three main problematic touchpoints were discovered, namely 1) Searching and Planning the charging journey, 2) Reservation journey, and 3) Issuing a tax invoice. These journeys were analysed through the SERVQUAL framework, inspecting its quality in five main areas including 1) Tangibility, 2) Reliability, 3) Assurance, 4) Empathy, and 5) Responsiveness.

Table 2 summarises the touchpoint of "Searching and Planning the Charging Journey." This journey consisted of two key aspects: 1) the interface of the EV charging application and 2) the ability to interact with the displayed EV charging stations. Therefore, the tangibility of this touchpoint was primarily digital, rather than physical.

According to the survey results in the previous section, users were generally able to locate EV charging stations but often struggled with interacting with the displayed information, which compromised the overall search and integration experience.

In terms of reliability, users reported inconsistencies between the actual availability of EV charging stations and the status shown

on the interface. This discrepancy indicated an unreliable service experience, as the lack of accurate information can diminish users' confidence in the charging process, undermining system assurance. The survey findings also suggested that the service provider may have overlooked the importance of delivering accurate, reliable information, failing to meet customers' expectations for quality. This reflected a gap of empathy in understanding customer needs, as the system's accuracy should be a priority to ensure a satisfactory user experience.

Table 3 summarised the touchpoint of the "Reservation journey." Similar to the reservation journey, the tangibility is assessed with a digital interface where the customer found difficulties in the status displayed and reservation function of the EV charging station. This was also linked with the reliability of the service where customers found the discrepancy between their application reservation and the actual charging station reservation. The service failed to reserve and perform a reservation as promised. It was also reported that the charger readiness was not aligned with reserved status. This deemed to be a negative of reliability area. In terms of assurance, the service fails to ensure customer success in achieving its reservation goals, specifically in enabling users to utilize reserved charging slots. This shortcoming undermined trust in the system and contributes to customer dissatisfaction. Additionally, it reflected a lack of empathy from the service provider, as there appeared to be no implemented assurance mechanism to guarantee customers' access to their reserved slots. This indicated a failure to recognise and prioritised customer needs, demonstrating a deficiency in the service provider's empathy toward its users. The responsiveness of this touchpoint could be concluded as negative due to the technical issues reported by users. This reflected a problematic service that fails to meet customers' needs in a timely and responsive manner. The issue was closely linked to the lack of real-time status alignment, which prevents the service from delivering accurate and up-to-date information to users when they request demonstrating poor responsiveness quality.

Table 4 summarised the SERVQAL of the tax issuance touchpoint. The analysis of tax issuance processes revealed several critical deficiencies across multiple service dimensions. Customers had expressed negative perceptions, largely due to the complexity and cumbersome nature of requesting tax invoices. Issues related to reliability are evident, as users report frequent inconsistencies in the receipt of invoices, resulting in a low average satisfaction score of 2.57 out of 5. These inconsistencies suggested a significant gap in reliable service delivery. Furthermore, the absence of mechanisms to ensure the successful issuance of tax invoices undermines trust, highlighting a deficiency in quality assurance practices. The inability to consistently meet fundamental customer needs, coupled with a lack of proactive measures to address the importance of accurate and timely tax documentation, indicated a shortfall in empathetic service provision. Additionally, delays and inconsistencies exacerbated customer frustration, underscoring inadequacies in the system's responsiveness

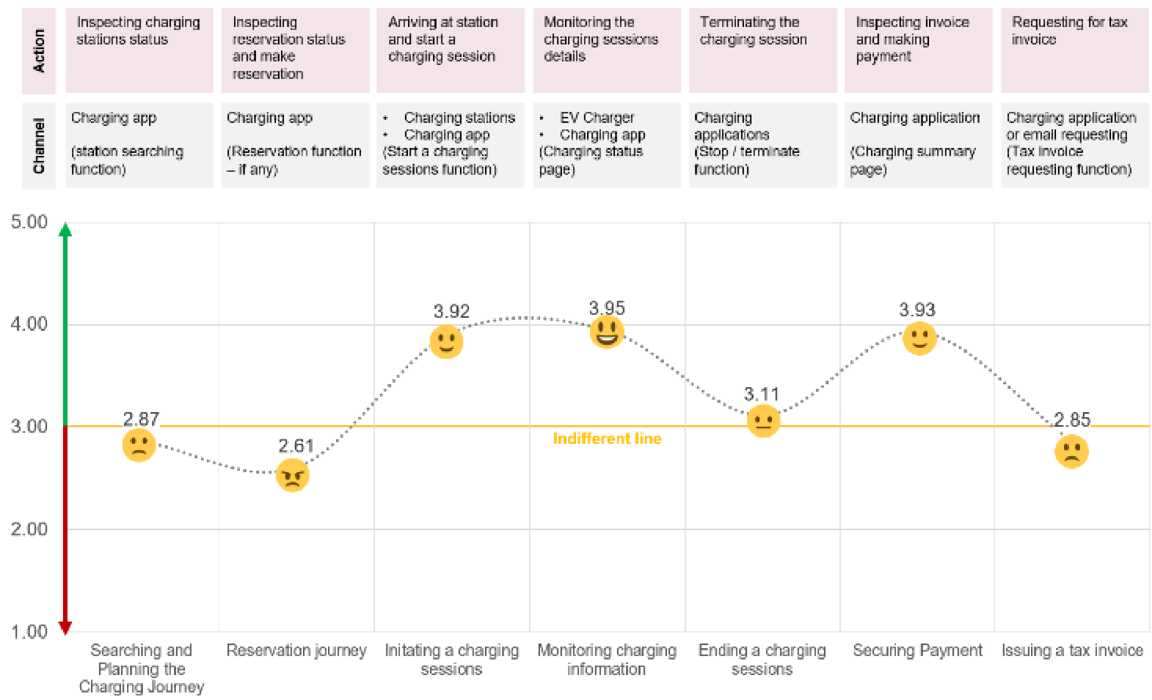

Fig. 4. Customer journey mapping result

Table 2. SERVQUAL analysis of Searching and Planning the Charging Journey.

Searching and Planning the Charging Journey		
Domain	Result	Supporting details
Tangibility	Negative	Although the majority of respondents in the survey reported positive experiences with location searches, a subset of participants indicated difficulties in interacting with the displayed locations.
Reliability	Negative	Users reported inconsistencies between the charger availability displayed in the application and the actual status of the chargers upon their arrival at the stations.
Assurance	Negative	Due to the inadequate accuracy of the displayed charger availability, users expressed decreased confidence in the overall charging experience.
Empathy	Negative	The survey results implied that the application provider may have overlooked the importance of accurately displaying charger availability to customers. Consequently, they appear to be operating the system without ensuring its reliability.
Responsiveness	Can not be concluded	Responsiveness can be a subjective experience that varies across users based on individual expectations and experiences. Moreover, the responsiveness issues might rooted in the application service provider and, therefore couldn't be judged according to the EV roaming perspective

Table 3. SERVQUAL analysis of Reservation Journey.

Reservation journey		
Domain	Result	Supporting details
Tangibility	Negative	Although the majority of respondents can be able to reserve a slot, it is reported that the reservation status and charger availabilities were not up to date. Moreover, participants reported difficulties in interacting reservation function and the presence of technical issues.
Reliability	Negative	Users reported discrepancies between the charger availability with their reservation. The platform failed to reserve the slot as promised by the application.
Assurance	Negative	When the charging station is not ready as promised, this further undermines trust in the system. This might lead to system doubtfulness from customers
Empathy	Negative	Due to there being no supporting evidence, this area is weak to conclude. However, the result of the survey could imply that there is no double check of the charger readiness, meaning the service provider failed to address customer needs in this area and provided no caring aspects for it.
Responsiveness	Negative	The presence of technical issues reported could imply the problematic responsiveness of the system. In addition, the lack of real-time updates or notifications when issues arise also indicates poor responsiveness

Table 4. SERVQUAL analysis of Tax issuance journey.

Tax issuance		
Domain	Result	Supporting details
Tangibility	Negative	The customer survey revealed that users encountered difficulties in requesting tax invoices, which were attributed to the complex and cumbersome process involved.
Reliability	Negative	Users reported inconsistencies in receiving tax invoices after completing payments, with an average score of 2.57 out of 5, indicating poor reliability of the process. Furthermore, the failure to provide requested tax invoices highlights a gap in service delivery.
Assurance	Negative	The potential inconsistency in tax invoice delivery undermines trust in the system, suggesting the absence of a mechanism to verify whether customers have received their invoices. This reflects a lack of robust quality assurance.
Empathy	Negative	The process falls short of meeting fundamental customer needs by failing to consistently deliver tax invoices as expected. This indicates a lack of understanding of the importance of these documents to customers and their reliance on the system to provide them accurately and promptly. This lack of acknowledgement of customer inconvenience, lack of customer need fulfilment, and lack of anticipating customer needs suggests a lack of empathy from the system.
Responsiveness	Negative	The inconsistency in tax invoice delivery may imply delays, leading to potential customer frustration. The low scores at this touchpoint further suggest that customers feel their needs are not being adequately met.

4.7.2. Root cause analysis

The Ishikawa framework was adopted as the basis for root cause analysis. Each diagram represented the analysis for the 1) Searching and planning journey, 2) Reservation journey, and 3) Tax invoice requesting journey respectively. According to the main contribution target of this research, which is to focus on improving roaming service, the following analysis was focus mainly on the roaming-related system and service workflow-related system, neglecting the qualitative quantity and experience design-wise. Therefore, the following was scope down the analysis areas into three areas including, tangibility, reliability, and responsiveness.

Fig. 5 demonstrated a potential cause-effect diagram for the searching and planning journey of EV charging stations, highlighting key issues affecting service quality. The tangibility concerned can be traced to three primary factors: 1) poor system performance of the EMSP, potentially stemming from the underlying system architecture, 2) integration challenges between the EMSP and CPO indicating difficulties in interacting with displayed stations; and 3) underperformed system performance of the EMSP application.

The reliability issues could be associated with five main causes. The first was the lack of synchronisation in availability data across the roaming network, which revealed that only basic charger status was synced, prone to discrepancies between roaming partners. This lack of synchronization leaded to potential deviations in availability data, exacerbated by the possibility of each party independently processing internal data without cross-network validation. Additionally, inconsistencies or inaccuracies in data transferring from CPOs (senders) to EMSPs (consumers) could also contribute to discrepancies in charger status and availabilities.

Responsiveness issues could be categorised into two domains: 1) performance from the EMSP application itself, and 2) integration-related challenges. Slow response times may originate from system latency within the EMSP's native application, possibly rooted in both back-end infrastructure and front-end functionalities. Furthermore, the application may appear unresponsive if it fails to retrieve necessary data from the CPO, which could prevent proper display and interaction with the charging station information.

Based on the evidence presented, it could be conceptualised that the challenges in the searching and planning journey for EV charging stations may stem from inaccuracies in charger status information. These inaccuracies were likely caused by a lack of integration between the charger availability reporting system and additional status layers, leading to discrepancies in the displayed charger status. As a result, customers were unable to accurately determine whether a charger was available for use or simply appears as such within the application.

This issue became particularly critical when native CPO-based customers and roaming customers arrived at the same station, potentially leading to conflicts over charging slots. The prevention of such conflicts relied on the CPO's system logic and its capacity to block interference from third-party access. However, there was currently no evidence of market implementation capable of effectively managing this scenario. Furthermore, this gap in integration complicated the troubleshooting process for service providers, as efforts to identify the root cause often reveal only charger rejection, without addressing the underlying issue. Ultimately, the mobile application, which served as the customer-facing interface, displayed incorrect information, resulting in user confusion and dissatisfaction.

Figure 6 demonstrated a potential cause-effect diagram, highlighting the potential root cause of the reservation journey. The tangibility issue could be traced by three main causes. Two out of three could be the result of the poor management of the EMSP including poor system performance, and lack of clear instructions. The poor system performance was the first possible cause in these areas contributing to the bad reservation function and leading to technical issues that subpar the user experience. This poor performance could also lead to deviation of the reservation availability. The poor experience of this touchpoint could also be rooted in the poor design by having unclear instructions. When the user received improper guidance during the process, this leaded to errors, confusion, and dissatisfaction with the reservation function. The back-end integration issue between EMSP and CPO could be another issue causing the bad tangibility of the reservation journey. For instance, while the EMSP interface may interact seamlessly with its back-end system, it may experience unstable connections with the CPO server. This instability could result in incomplete data retrieval, leading to missing or delayed information, such as charger availability. Such inconsistent integration may cause data omissions or inaccuracies in data transmission, ultimately resulting in the technical deficiencies reported by users.

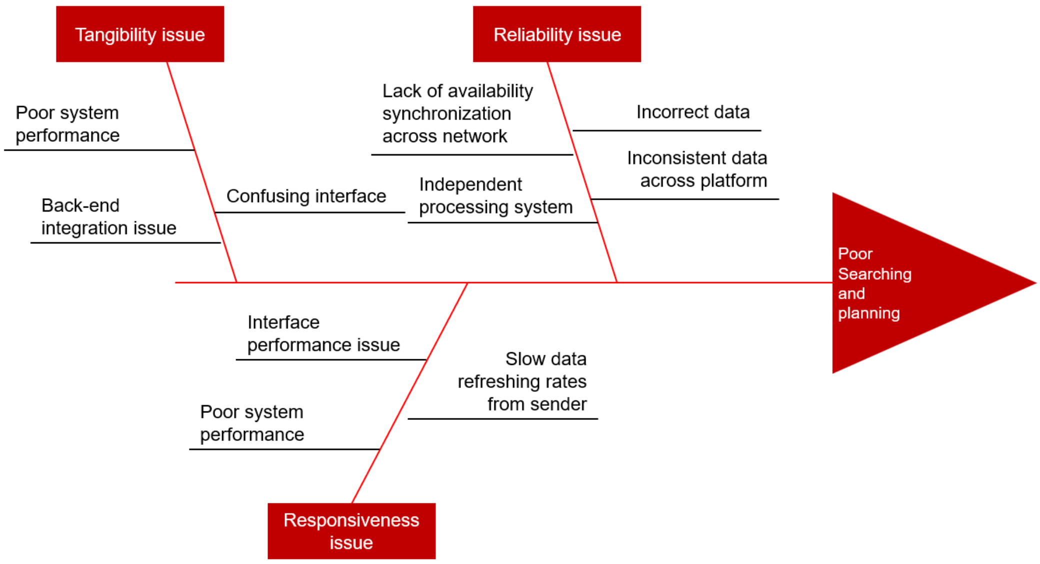

Fig. 5. Cause-effect diagram of the poor searching journey

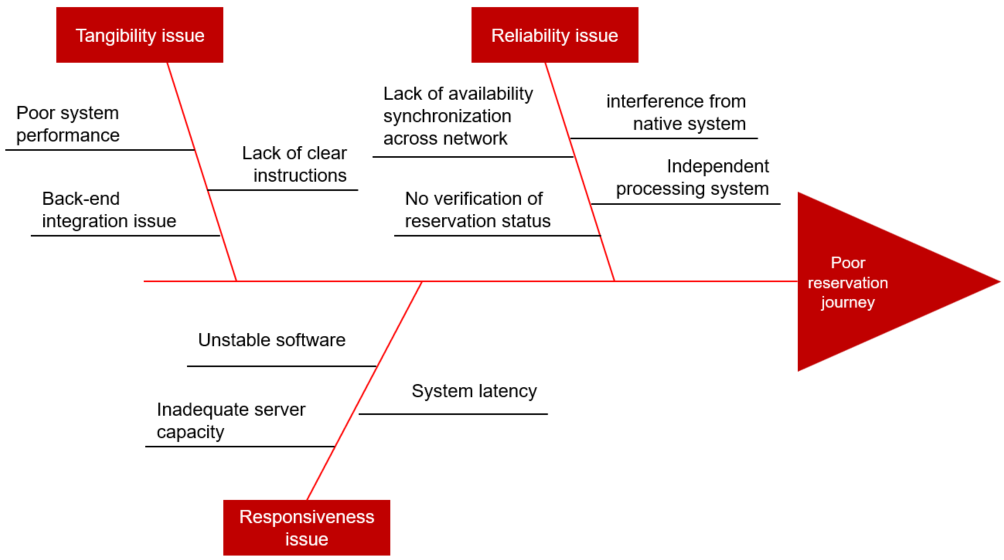

Fig. 6. Cause-effect diagram of the poor reservation journey

The reservation reliability issue could be comprised of four main issues, including 1) Lack of availability synchronization across the roaming network, 2) interference from the CPO-based users, 3) no verification or correctness assurance process, and 4) the EMSP and CPO may process its independent proprietary system. One possible root cause of the reservation reliability issue was the lack of synchronisation across systems. Users experienced discrepancies between charger availability and reservation status. This misalignment could stem from the inadequate implementation of availability synchronization. The absence of such implementation not only leaded to deviations in status synchronisation but also resulted in inconsistent data being displayed, confusing users. Additionally, evidence suggested that the availability data presented in the service application was not up to date, further confirming this issue, and ultimately affecting the reliability of the service.

This issue might also be rooted in the EMSP's internal processing. Two possible reservation journeys were explored: 1) using the OCPI-based command to reserve a charging slot and notifying the partner to synchronize the information across the network, and 2) the EMSP independently making a reservation on its proprietary platform, notifying only users on its native application. The EMSP may have adopted the second journey, making reservations independently. This leads to a misalignment between charger status and reservation availability, as the system does not fully reflect users' actual intentions, causing status deviations. Moreover, the issue may stem from the EMSP's implementation, such as a lack of verification processes and reliance on outdated information instead of real-time corrections. Implementing such measures could serve as an assurance function to ensure that reservation statuses are synchronized across the board. The incident where users encountered inaccurate charging status suggests that the EMSP and CPO may not have implemented this facility.

Finally, even if synchronisation measures were in place if the system was not designed to effectively enforce commands, reliability issues may persist. Interference from the native system could embody the situation where the native system undermined service reliability. Even though the user from EMSP reserves a slot, and the EMSP sends those commands to let the CPO acknowledge the intent, however, if the CPO allows another user apart from the reserved user to start charging, may be due to incomprehensive usage case or reluctance. As a result, the unreliability of the reservation would persist, further affecting the overall user experience.

Responsiveness issues comprised of three possible reasons, 1) Unstable interface, 2) System latency, and 3) inadequate server capacity. The instability of the interface was subject to each EMSP's capability to manage its touchpoint channel performance. Given the poor score reported in the previous section, this suggested underperformed interaction touchpoints. This may lead to frequent crashes, and freezes, and therefore affected responsive aspects of the journey. This also could be related to system latency which fosters unstableness. The delay of data retrieval from internal service or partner's service could also affect the readiness and responsiveness of the application and ultimately the journey. When the system took too long to process a request, the user might miss out on available slots or crash into another request. This latency could be rooted in the inefficient system architecture or inadequate server capacity. This root cause leaded to performance issues affecting both the back-end and front-end sides. With these issues the interface (EMSP application may face slow response times, errors in processing from running out of running time, or crashes.

In summary, the reservation issues could be conceptualised as stemming from several key areas. Tangibility issues arise from poor system design on the part of the EMSP, ambiguous user instructions, and back-end integration challenges. These factors contributed to suboptimal system performance and technical problems, such as inaccurate data and inconsistent user experiences. Reliability issues were driven by four main factors: lack of synchronisation across the network, absence of verification mechanisms, interference from CPO operations, and independent data processing implementations. These factors led to discrepancies between actual charger availability and the status perceived by customers, causing outdated information to be relayed to the system, resulting in confusion and unreliable service quality.

Responsiveness issues were linked to the instability of the EMSP interface, latency within both the EMSP and CPO systems, and insufficient server capacity. The unstable front-end interface, likely caused by system latency and server overload, negatively impacts perceived responsiveness, potentially causing users to miss or lose their reserved slots. Collectively, these factors degraded system performance and reduced overall customer satisfaction throughout the journey.

Based on the evidence presented, it could be conceptualised that the challenges in the reservation journey stem from the system architect-related issues, lack of actual status synchronisation, and lack of roaming enforcement throughout the system. This caused data inaccuracies leading to unreliable, unresponsive journeys.

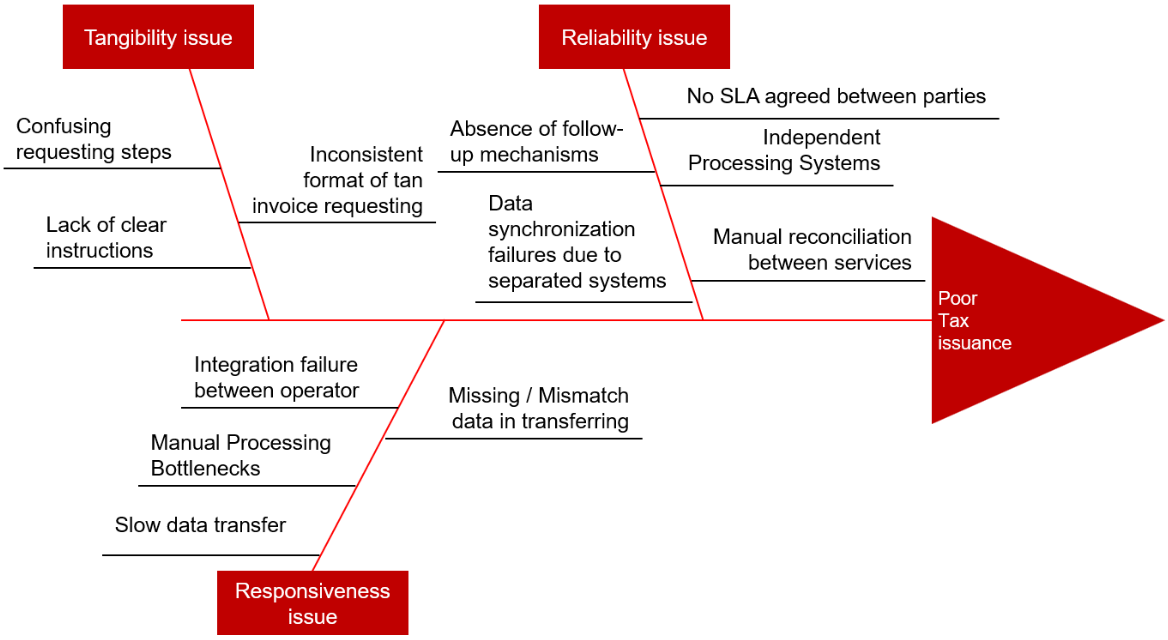

Fig. 7. Cause-effect diagram of poor tax issuance journey

Figure 7 illustrates the cause-effects diagram of Poor tax issuance, highlighting the three main focuses on reliability issues, tangibility issues, and responsiveness issues. It could be seen from the overall perspective that Poor tax issuance could be rooted in many more factors compared to the previous two journeys. However, it could be grouped into EMSP-based problems and integration-based problems. Customers encountered challenges in processing tax issuance requests. This may be attributed to EMSP-related factors, such as unclear requesting steps and a lack of clear instructions. These underlying issues impede customers' understanding of the process and contribute to confusion in their user experience. From an integration perspective, the tangibility problem may stem from inconsistencies in the format for requesting tax invoices. Such inconsistencies could further complicate the process, leading to varying user experiences across different roaming platforms, ultimately causing frustration and inefficiencies in the system.

Reliability issues examined in the survey reported low satisfaction. Users reported that they inconsistently received the tax invoice after requesting it. There were four possible root causes fostered in this research including 1) failures of data synchronization and transferring, 2) independent processing system, 3) Manual reconciliation between the service, and 4) absence of follow-up mechanisms.

Once users requested a tax invoice, their data were transferred from the EMSP (the platform used) to the CPO (the station owner) for the tax issuance process. If this process felt, user data might not be sent to the CPO, preventing the issuance of the tax invoice. This highlighted a failure in data synchronization and transmission between the two entities.

The implementation of this process relied on two possible approaches including 1) API integration for automated data exchange between systems or 2) manual data batch processing. Current market practices still predominantly rely on manual data transfer, which is prone to errors, data loss, and low operational efficiency. The independence of EMSP and CPO systems further complicates matters, as it necessitates additional manual work by operations teams, leading to delays in the process.

Another factor contributing to reliability issues was the manual reconciliation process. The involvement of human intervention could slow down tax invoice processing and introduce data inconsistencies, especially when systems are not fully integrated. Finally, the absence of a clear tax issuance agreement between EMSP and CPO means that EMSPs cannot provide customers with a committed timeline for when tax invoices would be issued, further exacerbating inconsistencies in response times and undermining the reliability of the overall service.

The responsiveness issues could be fostered by several factors of which most could be traced back to the previously mentioned reasons. The first potential factor causing responsiveness issues was slow response due to poor system integration. In the same way as the tangibility issue, the tangibility glitches might be rooted in the back-end processing as well as responsiveness. When the processing fails or is delayed in retrieving or sending data from the third-party partners, the application might not be responsive in a timely manner leading to customer dissatisfaction.

Additionally, slow data transmission due to system inefficiencies further exacerbated responsiveness issues. For instance, if the EMSP application was waiting for a "callback" from the endpoint, delays in data transfer between the EMSP and CPO could slow down the application's performance. This results in the EMSP's back-end receiving responded slower than anticipated, causing extended wait times for customers.

The current industry practice of relying on independent, manual processing introduced further bottlenecks, which slow down the tax issuance process and reduce overall system responsiveness. Lastly, with the independent processing and unalignment of the tax issuance format, this implementation was prone to missing or mismatching the data transfer. This also causes delays in the tax issuance process. Moreover, corrective manual intervention was required to solve the mismatching due to there would be no automated linkage for tax issuance. This root cause could directly impact how quickly the system could respond to user requests for tax issuance.

In summary, the root causes of the poor tax issuance journey could be grouped into three main areas including tangibility, reliability, and responsiveness. Tangibility issues—such as confusing steps, unclear instructions, and inconsistent formats across the roaming network—directly impact the customer's perception of the system's ease of use. These issues were further compounded by reliability challenges, which included the absence of an enforced service level agreement, a lack of follow-up mechanisms for both customers and the system and data synchronisation problems. These factors led to delays and disruptions in system operations, ultimately affecting customers' trust in the service's reliability. Additionally, these root causes contributed to responsiveness issues, driven by poor system integration, slow data transfer, and manual-based operations that were prone to bottlenecks. These inefficiencies reduced the system's overall responsiveness and negatively impacted the customer experience.

4.8. Service Model Alternatives

Based on the findings from the customer survey and the pain-point analysis, three key areas for improvement have been identified: 1) searching and planning for the charging journey, 2) the reservation journey, and 3) the tax issuance journey. To address these areas, a focus group discussion was conducted aiming to generate alternative options for the roaming service touchpoints. This research connected with industry experts from three companies that currently operate EV charging business in Thailand. Of these, two are private companies established more than five years ago, and another company was a subsidiary company of a state-owned enterprise. This group of experts were called "Charter". The Charter consists of eight people.

After the charter examined the problematic journey, they agreed that the first two journeys (searching and planning, and reservation) could be rooted in the charge point status issue. Due to the current roaming infrastructure, the charger status cannot be synced with charge point operators' reservation initiatives, the charter agreed that the second layer functions were in need to be implemented. Initially, there were three alternatives raised during the sessions including 1) No reservation module needed, 2) CPO to CPO with market standardised reservation module with enforcement, and 3) CPO to Hub with market standardised reservation module with enforcement. However, the charter agreed that the reservation model was needed for EV charger users; therefore, CPO should support this activity by enabling reservations throughout the network, eventually cutting off the first alternative.

The second-layer reservation module was designed to resolve charge point status discrepancies by updating the Open Charge Point Interface (OCPI) based charge point status according to the Charge Point Operator's (CPO) proprietary reservation system. This approach enabled integrating partners to retrieve more accurate charge point status information. Additionally, it provided the option for partners to create reservations through roaming networks and displayed them to end users in a standardised format across the roaming partner.

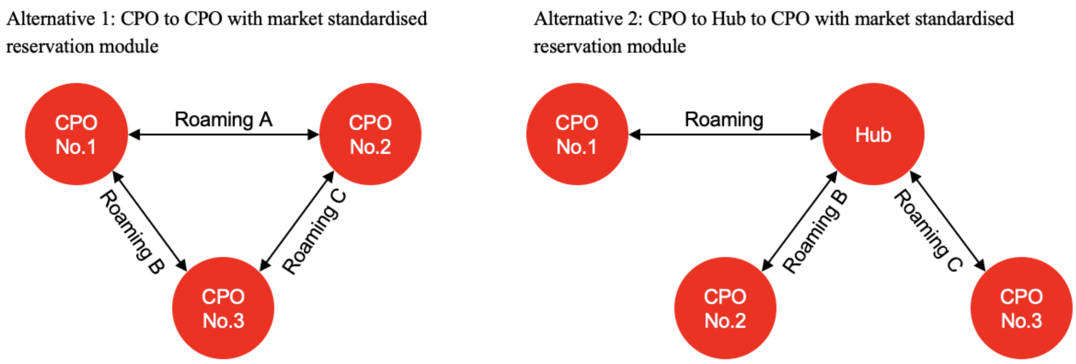

Fig. 8. Available service alternatives

The two alternatives for addressing the charge point status issue shared a common conceptual foundation but differed in their implementation approaches. Figure 8 illustrates the distinctions between these two alternatives. The alternative required CPOs to connect directly, while another solution proposed a hub to centralize those reservation roaming. Moreover, these alternatives were conceptualised as an "add-on" service, meaning that the implementer was responsible for aligning integration details directly with their chosen partners, without requiring conformity to a universal standard across the entire roaming network. In other words, implementers had the flexibility to integrate only with the formats they preferred. However, the group kept the implementation open as CPO-to-CPO integration and CPO to Hub to CPO. The service models could be summarised as shown in Figs. 9 and 10, respectively.

The second focal touchpoint pertains to the responsibility for tax issuance. According to Thai regulations, VAT-registered business entities providing goods or services were legally required to issue tax invoices. However, while this process was seamlessly implemented within individual networks, there was currently no standardised procedure for tax issuance across the roaming network in Thailand. The charter engaged in an in-depth discussion from various perspectives, including technical, operational, financial, and accounting considerations.

Two alternatives were proposed during the session: 1) the CPO, which physically delivered the service, would assume responsibility for issuing the tax invoice, or 2) the EMSP, which digitally provided the service, would issue the tax invoice to the end user. These alternatives presented a dilemma regarding which party should be accountable for tax issuance and the management of the associated costs. Additionally, technical integration was required to facilitate data transfer between the EMSP and the CPO for the purpose of generating tax invoices. The service blueprints for both alternatives were illustrated in Figs. 11 and 12, respectively.

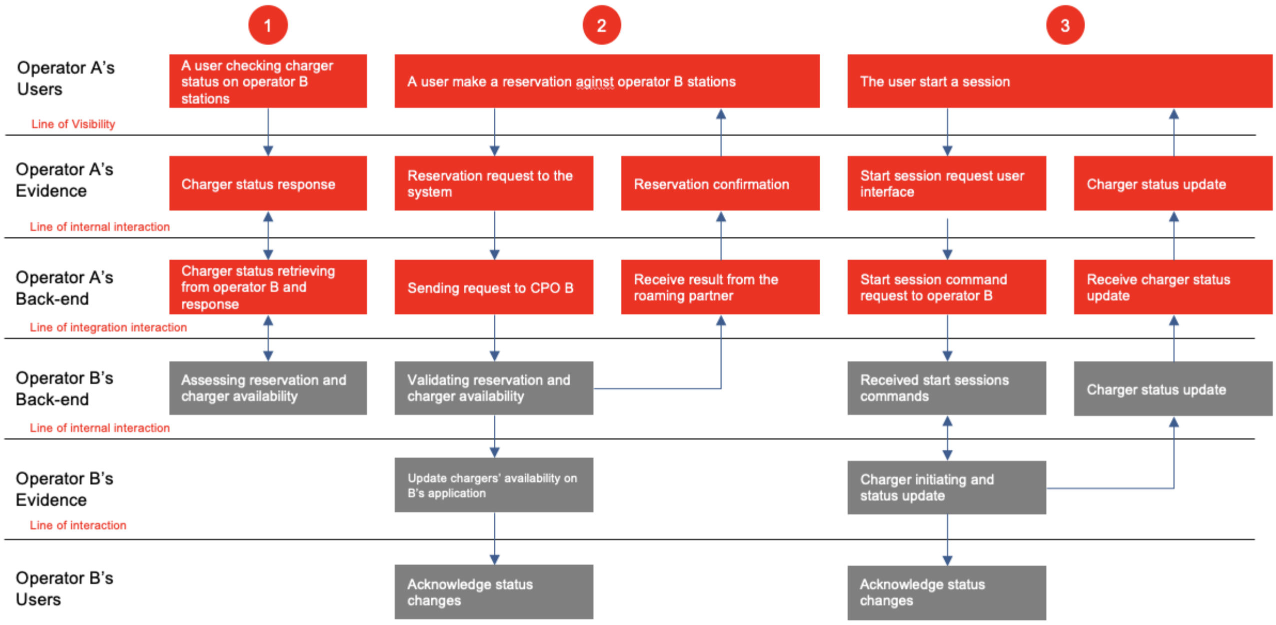

Fig. 9. Reservation alternative service blueprint CPO-to-CPO

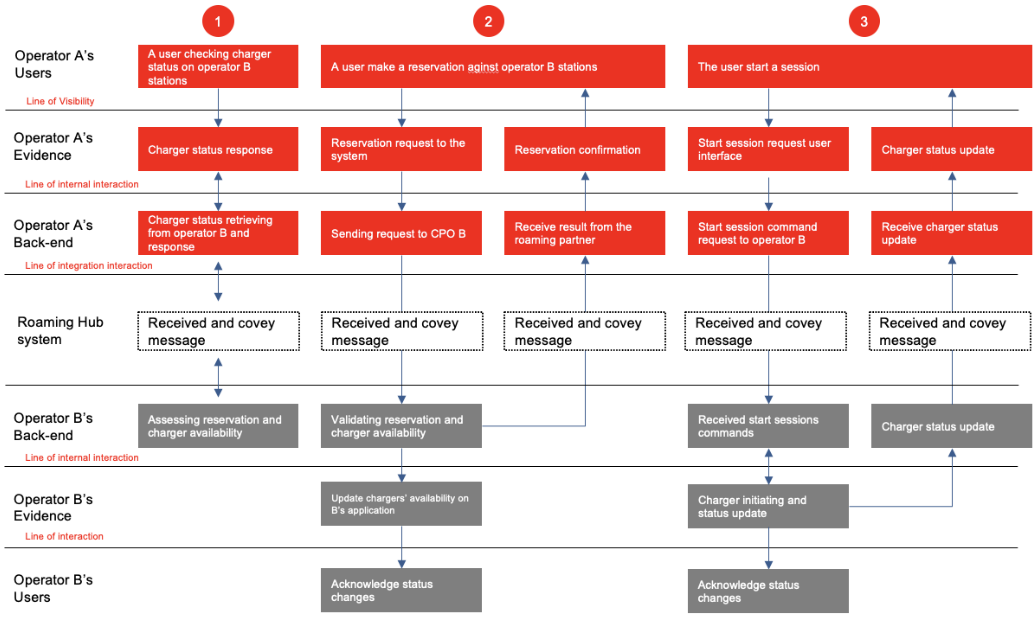

Fig. 10. Reservation alternative service blueprint CPO-to-Hub

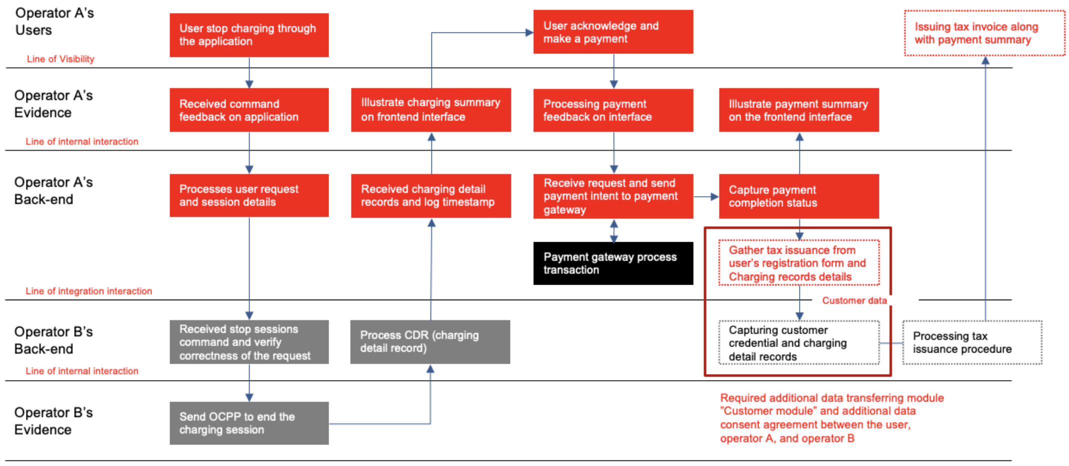

Fig. 11. Option A: Tax issuance alternative service blueprint CPO's responsibility

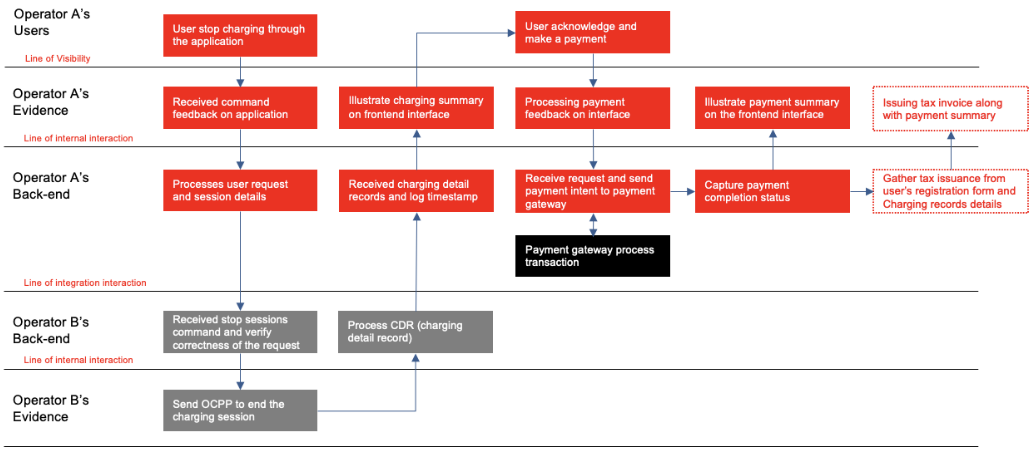

Fig. 12. Option B: Tax issuance alternative service blueprint CPO's responsibility:

After the charter commented on the user's pain point, the charter then discussed the pain point and operation improvement from operator touchpoints. It was reported apart from the new integration proposal and tax issuance responsibility, the reconciliation hurdles between operators had been highlighted. The charter possessed concerns regarding the scalability and additional workforce required in the large-scale implementation.

They concluded that the current payment system had been designed to be a manual reconciliation using the CDR as an indicator. However, they believed that those operating models were prone to human error and therefore proposed an additional alternative to improve the service from the operator's perspective.

The additional improvement focuses on payment integration between each operator. One member of the charter, with extensive experience in full-loop EV roaming, proposed a solution for integrating payment systems to automate fund reconciliation and routing. This approach could significantly reduce the operational workload of operators; however, it necessitates a mediator to connect the payment gateways of both parties. Notably, similar fund routing solutions have already been implemented in Thailand by several service providers, including Stripe, KBank, Omise, and 2C2P. The proposed solution addresses the ongoing challenge faced by operators, who were required to allocate additional resources for tracking financial activities related to roaming services and manually reconciling transactions based on agreements between operators. Consequently, two potential options emerged from the discussion: implementing payment integration or opting not to pursue it. The service blueprints for both options were outlined in Figs. 13 and 14, respectively. The process began with the same action of the user; however, the difference lay in the payment reconciliation process.

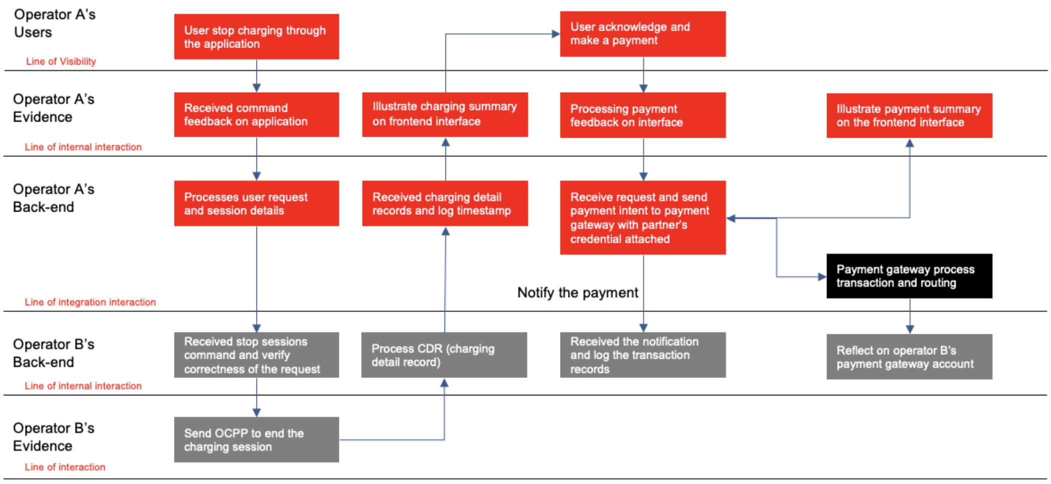

Fig. 13. Payment integration alternative service blueprint

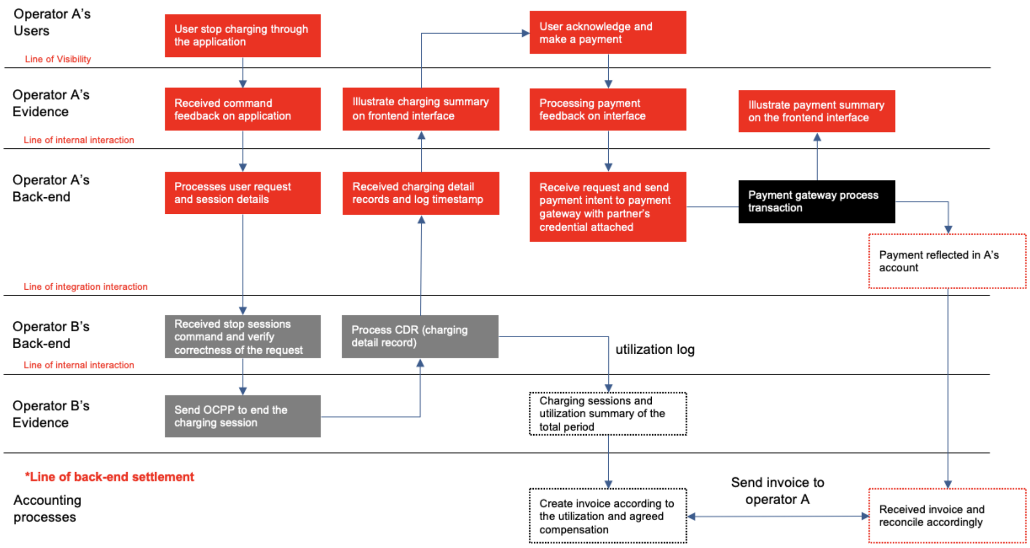

Fig. 14. Payment disintegration alternative service blueprint

4.9. Service Model Selection

4.9.1. Decision criteria establishment

This research connected with the same charter to conduct the second focus group on a different day. The result of the FAHP criteria establishment discussion is illustrated in Fig. 15. Expert participants agreed upon three major criteria attributes to justify the service model including Business Excellence (BE), Technical Excellence (TE), and Operational Excellence (OE). Sub-attributes to measure how strong the main attributes comprised Business Excellence (BE): (1) Revenue model flexibility (RM), (2) Cost management (CM), and (3) Partnership and

DOI:10.4186/ej.2025.29.8.37

Alliance (PA); Technical Excellence (TE): (1) Data Management and Analytics (DA), (2) Security (SE), (3) Technical sustainability, 4) Integration hurdles (IH); and Operational Excellence (OE): (1) Interoperability Performance (IP), (2) Customer support ability (CS), and (3) Operation sustainability (OS).

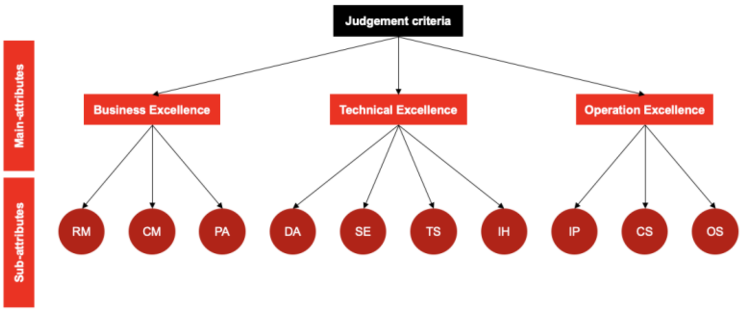

Fig. 15. FAHP criteria establishment.

4.9.2. Alternative model selection:

FAHP was implemented through a systematic approach involving several key steps: defining the decision criteria, constructing fuzzy pairwise comparison matrices, calculating fuzzy weights, and applying defuzzification techniques to derive rankings. Model can be described as M1 – M8 as shown in table 5. Based on the findings from the criteria establishment, the decision criteria and the overall fuzzy evaluation matrix were structured as shown in Fig. 16. Three main attributes were supported by nine sub-attributes. These decision criteria were utilised to select the most preferred second-layer EV roaming service model.

Table 5. SERVQUAL analysis of Tax issuance journey.

Model	Summary	Cost wise	Reservation system	Comments	Payment	Commets	Tax issuance	Comments
M1	Fixed flexibility with automated payment and transferred customer information, needed additional development development in central reservation system, payment part and taxing part	High Capex Low Opex	Centralised integration	- Single integration (Less integration hurdles) - Single point of failure - Indirectly connect to the end consumer (CPO) - requires central operator to allocate, incure more cost - more complex to control over infromation consumption,H8	Integrated payment system	- CPO receive revenue instantly - Less operation step - Automated system - easier to scale up operation	CPO issuing tax invoice	- Tax liability lies over CPO - CPO receive customer information - Needed additioanl development
M2	Fixed flexibility with automated payment. additional development development in central reservation system,and payment part	Medium to High Capex Low Opex	Centralised integration		Integrated payment system		EMSP Issing tax invoice	- No additional developmet required - CPO don't receive any customer data
M3	Fixed flexibility yet required additional process with transferred customer information, needed additional development in central system and taxing part	Medium to higjh Capex Medium Opex	Centralised integration		Non-integrated payment system	- Additional process in billing - Manual process - Need additional care over information correctness	CPO issuing tax invoice	- Tax liability lies over CPO - CPO receive customer information - Needed additioanl development
M4	Fixed flexibility yet no additional development required. Easiest way to implement	Medium Capex Medium Opex	Centralised integration		Non-integrated payment system		EMSP Issing tax invoice	- No additional developmet required - CPO don't receive any customer data
M5	Highest Flexiblity with automation system, and transsfered customer information, yet need additional development in payment part and tax part	Medium to High Capex Low Opex	Decentralised integration	- P2P integration (More integration hurdles) - Fault tolerance - Easier Customise for commercial scheme - Parties can control information consumption easier	Integrated payment system	- CPO receive revenue instantly - Less operation step - Easier to scale up operation	CPO issuing tax invoice	- Tax liability lies over CPO - CPO receive customer information - Needed additioanl development
M6	Highest Flexiblity with automation system, Yet no customer data transferred and need additional development in payment part	Medium Capex Low Opex	Decentralised integration		Integrated payment system		EMSP Issing tax invoice	- No additional developmet required - CPO don't receive any customer data
M7	Some flexibility yet required additional process with transferred customer information, needed additional development	Medium - low Capex Medium Opex	Decentralised integration		Non-integrated payment system	- Additional process in billing - Manual process - Need additional care over information correctness	CPO issuing tax invoice	- Tax liability lies over CPO - CPO receive customer information - Needed additioanl development
M8	Some flexibility yet no required additional process	Low Capex Medium Opex	Decentralised integration		Non-integrated payment system		EMSP Issing tax invoice	- No additional developmet required - CPO don't receive any customer data

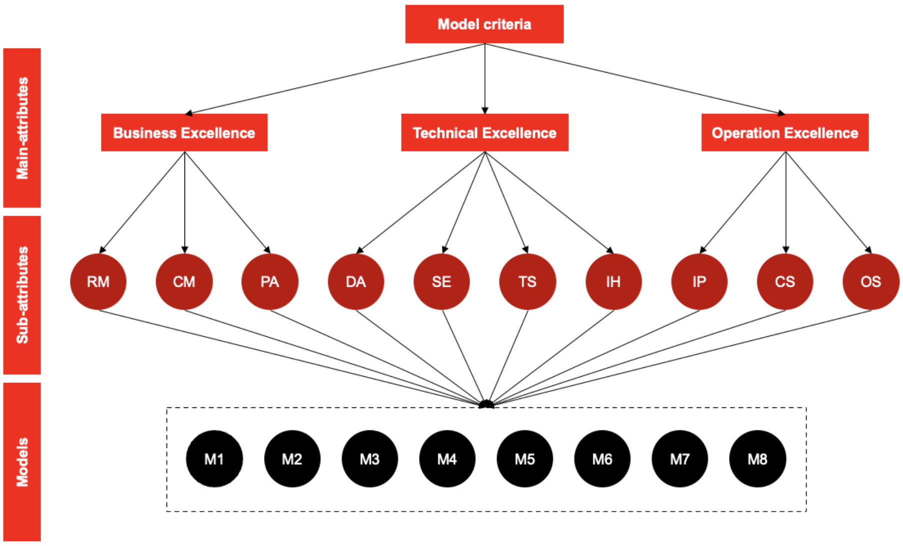

Fig. 16. Overall fuzzy evaluation model.

To conduct this scoring session, this research conducted another focus group discussion session, incorporating with same charter group in the later day. Experts were allowed to input their insights through the Nominal Group Technique [53]. The Goal Matrix in Table 6 indicates that the most preferred service model was Model M6 which achieved the highest FAHP score. Model M6 was considered the optimal choice for an EV roaming service model due to its strong balance between business and operational efficiency. In addition, Model M6 could be conceptualized as featuring a highly flexible revenue model with a decentralized structure, where CPOs integrate directly with each other. Therefore, operators could make negotiations over its compensation for the roaming freely. This model was enhanced by an automated billing system to streamline reconciliation processes. In this configuration, the responsibility for tax issuance was assigned to the EMSP, which helps to minimise development costs and reduce the complexity of data transfers. In summary, there were seven steps that a user would experience when utilising the charging service as follows 1) The user searches for a charging station, 2) The user makes a reservation, 3) The user initiates a charging session and monitors its status, 4) The user ends the charging session, 5) The user processes payment based on the received invoice, 6) The system generates a receipt for the user, and 7) The system generates an electronic tax invoice (E-tax) for the user. The M6 model then serves as the primary conceptual journey framework for technology acceptance in this study in further section.

Table 6. FAHP alternative grouping scores.

Tiers	Model	Score
1st tier	M6	0.392
	M5	0.256
2st tier	M7	0.148
	M8	0.107
3st tier	M1	0.036
	M2	0.032
	M3	0.018
	M4	0.003

Figure 17 outlined the customer charging journey in two primary stages: (1) Pre-charging and (2) In-charging. The Pre-charging stage involved location searching and reservation. In this stage, a user from EMSP A browsed a list of charging stations and selected station B. The user then initiated a reservation at station B, which confirmed the reservation with EMSP A and updated the status across networks by notifying other EMSPs of the station's "Reserved" or "Unavailable" status. Upon arriving at station B, the user from EMSP A authenticated via A's server, and EMSP A authorised the session through OCPI integration, requesting permission to initiate charging. Station B validated the request, and upon approval, responded to EMSP A, granting access for the user to begin charging at station B. During this process, station B updated the status from "Reserved" to "Charging" and communicated this to its roaming partners. Finally, by model 6, EMSP A managed the payment for the session and issued a tax invoice.

DOI:10.4186/ej.2025.29.8.37

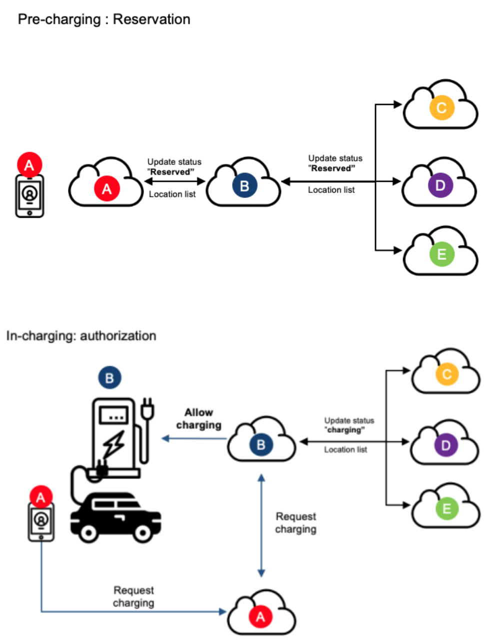

Fig. 17. Selected customer journey (M6 model).

4.10. Model Validation

This section aimed to validate user acceptance of the proposed EV roaming service model by leveraging the findings from previous sections as a foundation and applying the Technology Acceptance Model (TAM) as the evaluation framework. The research adhered to the original methodology by 1) designing the TAM constructs, 2) validating the survey questions, 3) conducting empirical data collection through surveys, and 4) employing statistical analysis techniques. AMOS, a Structural Equation Modelling (SEM) technique, was used to analyse the relationships and interpret the results.

4.10.1. Construct establishment

In the formulation of the TAM constructs, the research drew on TAM-related literature and adopted validated constructs from [32]. The construct items were adjusted to align with the EV roaming model, ensuring that the study's objectives were met while maintaining the validity and integrity of previous validations. Additionally, these survey constructs were validated using the IOC technique. There were 14 items measured using a 5-point Likert scale. These constructs were categorised as follows: three items for Attitude Toward Using, four items for Perceived Usefulness, four items for Perceived Ease of Use, and three items for Behavioural Intention to Use.

The survey constructs were administered by eight surveyors consisting of five business developers, two service designers and the researcher, in collaboration with one of the top five EV charging station operators in Thailand. A total of 300 responses were collected from Thai EV drivers. After data cleaning to eliminate outliers and unintentionally completed surveys, the final dataset consisted of 258 valid responses. Given the ten-times rules of sample size, the remaining response exceeds the threshold number (14 variables require 140 sample responses) and therefore could be treated as acceptable for SEM.

4.10.2. Measurement Distribution Analysis

To ensure the data was symmetrical, correlation, and multicollinearity, normality tests and bivariate matrices were examined. The key indicators including Mean, Standard deviation, variance, Skewness, and Kurtosis were considered acceptable, indicating approximately symmetric distribution. In addition, the multicollinearity test was performed using Pearson's correlation coefficient method. Table 7 illustrates the bivariate correlation matrix where it is observed, ranging from 0.258 to 0.764 with 0.01 significant level. These values deemed to be lower than 0.8 proved no multicollinearity problem. As a result, the data could be considered as a symmetric distribution possessing no multicollinearity potential issue, indicating a suitable dataset for SEM.

Table 7. Bivariate Metrix of SLERTAM.

	ATT1	ATT2	ATT3	PU1	PU2	PU3	PU4	PEOU1	PEOU2	PEOU3	PEOU4	BI1	BI2	BI3
ATT1	1													
ATT2	.612**	1												
ATT3	.552**	.588**	1											
PU1	.431**	.367**	.327**	1										
PU2	.378**	.326**	.352**	.541**	1									
PU3	.258**	.284**	.303**	.493**	.649**	1								
PU4	.337**	.349**	.376**	.579**	.706**	.664**	1							
PEOU1	.319**	.304**	.295**	.414**	.446**	.352**	.456**	1						
PEOU2	.362**	.327**	.347**	.382**	.427**	.354**	.452**	.681**	1					
PEOU3	.320**	.310**	.313**	.374**	.387**	.306**	.388**	.635**	.663**	1				
PEOU4	.338**	.317**	.323**	.380**	.317**	.273**	.400**	.563**	.632**	.701**	1			
BI1	.482**	.437**	.462**	.524**	.544**	.420**	.506**	.478**	.508**	.475**	.451**	1		
BI2	.433**	.347**	.349**	.435**	.452**	.340**	.423**	.425**	.504**	.368**	.377**	.764**	1	
BI3	.466**	.406**	.396**	.474**	.498**	.371**	.477**	.419**	.498**	.386**	.410**	.751**	.744**	1
**. Correlation is significant at the 0.01 level														

Table 8. Cronbach's alpha and Corrected item-total correlation analysis of SLERTAM.

Latent variables	Corrected Item-Total Correlation	Cronbach's Alpha
	(>0.3)	(>0.7)
Attitude toward using		0.807
ATT1	0.654	0.738
ATT2	0.680	0.711
ATT3	0.636	0.755
Perceived Usefulness		0.861
PU1	0.608	0.860
PU2	0.747	0.805
PU3	0.702	0.824
PU4	0.773	0.793
Perceived Ease of use		0.879
PEOU1	0.708	0.856
PEOU2	0.758	0.838
PEOU3	0.770	0.831
PEOU4	0.719	0.852
Behavioural intention to use		0.901
BI1	0.811	0.853
BI2	0.806	0.858
BI3	0.796	0.866
Total 14 scales		

4.10.3. Data set reliability analysis

The reliability of the 4 latent variables with 14 observable variables, based on a total sample size of 258 respondents, was assessed using Cronbach's Alpha. As shown in Table 8. All constructs demonstrated adequate reliability, with scores ranging from 0.711 to 0.755 for Attitude toward using, from 0.793 to 0.860 for Perceived Usefulness, from 0.831 to 0.856 for Perceived ease of use, and Behavioural intention ranging from 0.853 to 0.866, exceeded acceptable value of 0.7. Additionally, the corrected item-to-total correlation values for all items ranged from 0.608 to 0.811, surpassing the acceptable criteria of more than 0.3. These high Cronbach's Alpha and corrected item-total correlation values indicated good internal consistency and were positively associated with other measures, proving the dataset's reliability and suitability for further analysis.

4.10.4 Exploratory factor analysis

This section examined the SLERTAM model through the lens of factor analysis. This technique ensured the statistical correctness of the structure, especially in discovering the underlying relationship between measured variables. Utilising the principal component analysis (PCA) to extract components and transform the original variables into a new set of uncorrelated variables along with varimax rotation to lower the focusing dimensions, the structure was then grouped into the strongest coordinate axis.

The first step was to ensure the suitability of the dataset. Kaiser-Meyer-Olkin (KMO) was conducted to evaluate the extent to which the variance in the data was shared among variables and could be factored, as well as Bartlett's Test to evaluate whether the data were appropriate for factor analysis by comparing the difference between correlation matrix and identity. By having a KMO value (Table 9) of 0.911 leaning toward 1.00 having a chi-square of 2133.137 with a significant level of 0.000* which was lower than the 0.05 acceptance cut-off value. This implied that there were some relationships between the variables and the factor analysis was useful to conduct further analysis.

Communality analysis was conducted to help in understanding the strength of the relationship between variables and factors. It indicated how much a variable contributes to or shares in the variance with the factors identified in the analysis. Table 10 showed the results that communality's initial values were equal to 1.00 and the extractions range between 0.563 to 0.862 being more than 0.40 were considered stable and acceptable cutoff values indicating robust relationships with other variables within the factor model.

DOI:10.4186/ej.2025.29.8.37

Table 9. KMO and Bartlett's Test of SLERTAM.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.911
Bartlett's Test of Sphericity	Approx. Chi-Square	2133.137
	df	91
	Sig.	.000

Table 10. SLERTAM model Principal Component Analysis.

	Initial	Extraction
ATT1	1.000	.715
ATT2	1.000	.761
ATT3	1.000	.701
PU1	1.000	.563
PU2	1.000	.759
PU3	1.000	.765
PU4	1.000	.784
PEOU1	1.000	.699
PEOU2	1.000	.749
PEOU3	1.000	.788
PEOU4	1.000	.736
BI1	1.000	.824
BI2	1.000	.860
BI3	1.000	.823

The results of the rotational component matrix are shown in Tables 11 and 12. Four components were established, and all 14 constructs align separately from each distinct attribute, namely Attitude toward using, Perceived usefulness, Perceived Ease of use, and Behavioural intention to use. From the factor loading of each component, it could be seen the factor loading range from 0.603 to 0.851, acceptable with a greater than 0.4 cut-off value and there were no cross-loading problems with these constructs by having the loading of each construct greater than 0.2 of the second most loading, meaning these components were stable. In addition to the component validity, the cumulative variance ranging from 48.417% to 75.197% (greater than 60%), along with eigenvalues scored ranging from 1.016 to 6.788 (greater than 1) both were in the acceptable cut-off value according to Kaiser's rule [54].

Table 11. Rotated component matrix of SLERTAM

	Component			
	1	2	3	4
ATT1				.764
ATT2				.830
ATT3				.784
PU1		.603		
PU2		.786		
PU3		.851		
PU4		.806		
PEOU1	.753			
PEOU2	.771			
PEOU3	.846			
PEOU4	.811			
BI1			.752	
BI2			.860	
BI3			.804	

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Based on the exploratory factor analysis, it can be concluded that the SLERTAM comprised four main components Attitude toward Using, Perceived Usefulness, Perceived Ease of Use, and Behavioural Intention to Use. These components, derived from a rotational component matrix, had cumulative variance percentages ranging from 48.417% to 75.197%, all exceeding the threshold of 60% and eigenvalues between 1.016 and 6.778, all exceeding the threshold of 1.0 with no cross-loading problems. These components could be considered as stable as they pass all cut-off thresholds and statistically be able to refer to valid constructs.

Table 12. Total Variance Explained by SLERTAM.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.778	48.417	48.417	6.778	48.417	48.417	2.977	21.263	21.263
2	1.425	10.179	58.596	1.425	10.179	58.596	2.813	20.096	41.359
3	1.308	9.341	67.937	1.308	9.341	67.937	2.448	17.488	58.847
4	1.016	7.260	75.197	1.016	7.260	75.197	2.289	16.350	75.197

4.11. Confirmation Factor Analysis (CFA)

Figure 18 illustrates the standardised estimate of the SLERTAM CFA model after modification index adjustment. This model comprised four latent variables, namely ATT, PU, PEOU, and BI, and a total of 14 observed variables. The finding of CFA indicated the "Good fit" of the second order CFA (including latent variable), proven by the following criteria Chi-Square statistic was 77.794, df. = 69.0, Chi-square/df. = 1.127 < 3.0. The model acceptance was also supported by the acceptable values of GFI, AGFI, CFI, IFI, NFI, TLI, RMSEA, and RMR.

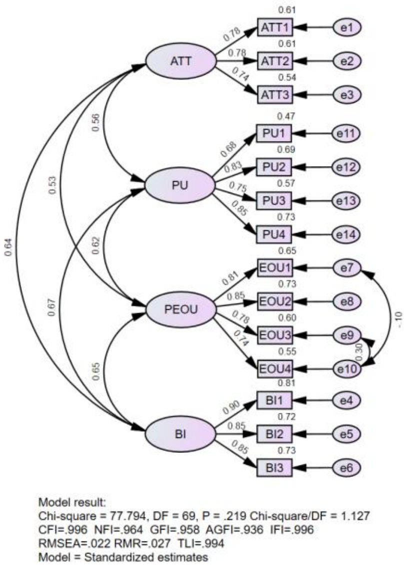

Fig. 18. CFA model.

The discriminant validity test was a crucial part of testing the construct. It was tested through the relationship of Average Variance Extracted (AVE), Maximum Shared Variance (MSV), and Average Shared Variance (ASV). The result supported that the structure reliability (Composite Reliability) of the latent variables was acceptable, ranging from 0.81 to 0.90 which was greater than the cut-off threshold of 0.7. In addition, all latent variables' AVE lay in the acceptable range of 0.59 to 0.75 more than 05, proving that all latent variables had convergence validity. The CFA model of the SLERTAM appeared well-specified with, good model fit, positive Construct Reliability, Convergent Validity, Discriminant Validity, moderate to strong factor loadings, and statistically significant reliability. This suggested that the latent variables (ATT, PU, PEOU, BI) were well-represented by their respective observed variables, and the model provided a good explanation of the data. Hence, this model was worth approaching toward the Structural Equation modelling.

4.12. Structural Equation Model (SEM)

The structural equation model (SEM) was employed to analyse the relation between each latent variable to shed light on the behavioural intention to use the second layer of the proposed EV roaming model. Fig.19 illustrates the SEM model which is adjusted from the validated construct from the previous section. This model was structured according to the proposed conceptual framework of the TAM. PEOU was the only exogenous variable, that predicted influence on PU and ATT. There were three endogenous variables namely perceived ease of use (PU), attitude toward using (ATT), and behavioural intention (BI) where both PU and ATT influence BI which was the last predictor, at the same time PU could also influence ATT.

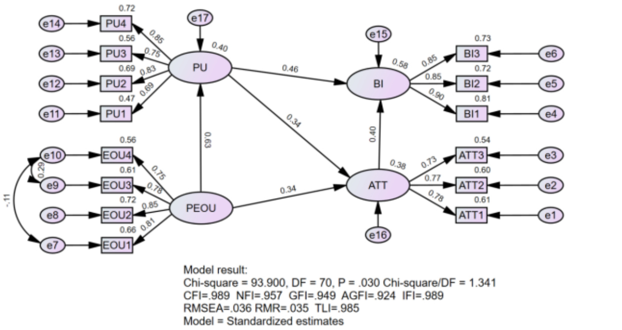

Fig. 19. SEM model of SLERTAM.

4.13. SEM - Model Modification

Model modification was employed in the SEM to improve the model fit, by adding more covariance between the error of the observed variable to revise an initial model based on statistical and theoretical considerations. The goal of model modification was to improve the model fit, making it a better representation of the underlying structure of the data. With no further investigation on the effect between each construct, this research reserved the covariance to be added internally in each construct as it evaluates the same construct. By examining the modification indices of the initial model, five recommended parameters emerged based on internal adding covariance guidelines. The result after modification is shown in Fig. 20. The model fit resulting from the modified model was improved. As a result, the modified SEM model was suitable and compatible with the empirical implication analysis.

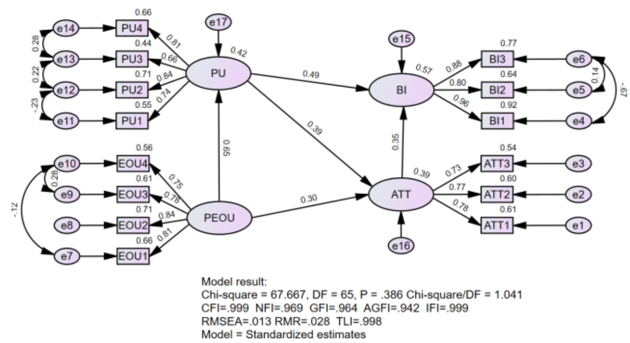

Fig. 20. Modified SEM model

4.14. SEM - Path Analysis

To focus on the TAM relationship, the SEM could be simplified of the referenced TAM model (Fig. 21). This model focused on only the latent variables, i.e., Perceived Ease of Use, Perceived Usefulness, Attitude toward using, and Behavioural intention, and the relationship between each latent parameter. To examine the relationship between the parameters and validate the hypothesis according to the TAM framework, path analysis was employed. The data demonstrates that the estimated path coefficient between 1) Perceived Ease of Use and Perceived usefulness of 0.649, 2) Perceived Usefulness and Attitude toward using of 0.390, 3) Perceived Ease of Use Attitude toward using of 0.295, 4) Perceived Usefulness and Behavioural intention of 0.491, and 5) Perceived Usefulness and Behavioural intention of 0.355. These path coefficients were statistically significant at ($p<0.001$) indicating a strong significance. These results were reliable and deemed creditability and could be used in the interpretation of the path analysis. Therefore, the hypothesis of H3, H4, H5, H6, and H7 were supported, and this model relation could be interpreted according to TAM.

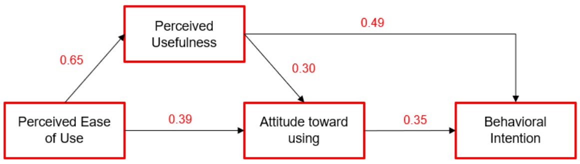

Fig. 21. new TAM conceptual model.

4.14. Model Interpretation

Table 13 summarises the calculated averages for each category, all on a five-point scale. These findings suggested that EV drivers in Thailand view the new system as both useful and easy to use. The positive scores for PU and PEOU contributed to a favourable Attitude Toward Using the system, which, in turn, predicted a positive Behavioural Intention to Use (BI). A BI scored above 3 out of five, indicated a likelihood of actual adoption of the technology. Moreover, the correlation also indicated that perceived usefulness (PU) was the strongest factor for Thai people in considering actual usage.

Table 13. Summary variable score from TAM survey

Attributes	Average mean score
Perceived Ease of Use	3.81
Perceived Usefulness	3.77
Attitude toward using	4.07
Behaviour Intention	3.61

4.15. Discussion

When reflecting on the new conceptual roaming model with Stickdorn's [50] service design, it could be concluded that the conceptual model resonates well with service design characteristics. Table 14 matches the characteristics of the new conceptual roaming model and the service design philosophy. There are five principles of service design, and this section derives and reflects the new service model characteristics with those principles.

1) The solution must be user-centric: This model is rooted in customer pain points on the current practice of customers with validated needs from the survey.
2) The solution must be co-creative incorporating not only end-users but also other stakeholders: This model is the result of co-creation not only with the end users receiving feedback from market research through surveying but also Charge point service providers who performing roles in ideating alternatives and deciding which is the best solution for them.
3) The design process should be arranged and validated in sequences: This research adopted, two Dimond frameworks, one of the design thinking for service design is to streamline the sequence of the design process, starting from defining the target, identifying the root cause, solution formulation, and solution consolidation.
4) The design must create artefacts: The new service model is designed to regulate the current workflow by enforcing reservations throughout the roaming network, which could be reacted as an artefact from this new roaming service model.
5) The service must not only focus on its outcome but the surrounding environment: The new service model is designed to incorporate throughout the EV charging-related stakeholders, not only from the proprietary user but all roaming users. This service also allows service providers to transfer crucial data such as real-time charger availability, and reservation availability to sync up their application displayed to serve their proprietary users. Moreover, the reconciliation hurdles of service providers are also handled by proposing options for integrating the payment system.

Table 14. Service design principal refection on the new conceptual service model.

Service design principles	Characteristic of the new conceptual EV roaming service model
User-centric	This model is rooted in customer pain points on the current practice of customers with validated needs from surveys.
Co-creative	This model is the result of co-creation not only with the end users receiving feedback from market research through surveying but also Charge point service providers which perform roles in ideating alternatives and also deciding which is the best solution for them.
Sequencing	This research adopted two Dimond frameworks, one of the design thinking for service design is to streamline the sequence of the design process, starting from defining the target, identifying the root cause, solution formulation, and solution consolidation.
Evidencing	Even though the new conceptual design hadn't been implemented, it is designed to affect the current workflow by enforcing reservations throughout the roaming network, which could be reacted as an artifact from this new roaming service model.
Holistic	The new service model is designed to incorporate EV charging-related stakeholders, not only the proprietary users but also roaming users. This service also allows service providers to transfer crucial such as real-data time charger availability, and reservation availability to sync up their application displayed to serve their proprietary users. Moreover, the reconciliation hurdles of service providers are also handled by proposing options for integrating payment systems. Lastly, the additional layer also considers operation excellence in streamlining tax issuance procedures.

5. Conclusion

This research addresses the research objective of proposing a conceptual roaming model for Thailand, driven by design thinking and service design approaches. This model is fostered by the co-creation of both End-users (EV drivers) and Service Operators (CPOs and EMSPs), providing actual feedback and domain expertise insight. This additional layer aims to address both customer hurdles and charge point operators' hurdles. The main pain points of these stakeholders are rooted in the data synchronisation accuracy leading to wrong display and ultimately customer misunderstanding and service interruptions. This issue is dealt with by implementing the second layer (additional infrastructure) on top of the OCPI roaming system, to customise and handle the uniqueness of EV drivers and service operators. Specifically, syncing reservation status and enforcement throughout the network is a key contribution to the new standard practice. This allows not only operators to sync up their actual chargers' status with reservation status consideration but also allows customers to see and understand the overall accessible stations within one application, addressing customer pain points of browsing through multiple applications. Moreover, the additional layers also consider how CPOs operate smoothly by streamlining the reconciliation processes and customer tax invoice issuance procedures.

Board academic instruments both quantitative and qualitative instruments are adopted and utilised to create the new conceptual model, which aims to maximise the creditability of the model. The research methodology follows the guidelines of the service design paradigm, applying the design thinking process on the double Dimond framework, and the core characteristic of the conceptual model aligns with the five principles of service design. The research starts from 1) defining the process by conducting a literature review and market research, to understand the overview of the current industrial practice, 2) identifying the stage to consolidate the main addressable target by conducting in-depth analysis through customer journey analysis, service quality assessment, and root cause analysis, 3) alternative establishments to broaden possibility of solution solving through focus group discussion, and lastly 4) Consolidate the solution and validate acceptance through FAHP for CPOs - EMSPs and Technology acceptance model for the end users. This research adopts quantitative instruments including IBM SPSS and AMOS in quantitative analysis and model validation, especially in the TAM process conducting SEM.

These applications contribute to both academic advancement and practical practices. In regard to academic contribution, this research introduces the service design paradigm into the EV charging domain, extending FAHP, TAM, and SEM into new areas of conceptual service design and yielding novel insights from correlations derived within TAM model relationships in respect of EV service adoption. In regard to practical practice contribution, this research introduces a new conceptual model to the industry, integrating academic knowledge and industrial-specific insights, tailored for the

Thai EV market. This model addresses the unique needs of Thai EV drivers and service operators in Thailand. Moreover, this research also yields insights into customer key considerations in technology adoption, which might be beneficial for operators' service development.

References

[1] EVAT. (2023). Thai Electric Vehicle Outlook 2023, evat.or.th. [Online]. Available: http://www.evat.or.th/15708256 /current-status (Accessed: 29 October 2023).

[2] R. Nitipathanapirak, Y. Suthirapojn, and C. Sripratum, *New Chapter of Thailand's Automotive Industry: from ICE to EV*. Bangkok: Thailand Board of Investment, 2023.

[3] IEA, I. (2022). *Global EV Outlook 2022*. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2022 (Accessed: 29 October 2023).

[4] EVAT, *EVAT Charging Consortium Meeting 19 OCT 2023*. Bangkok: EVAT, 2023

[5] SHARGE, "Projected EV growth in Thailand. Internal SHARGE report," Unpublished.

[6] S. Wongsunopparat and P. Cherian, "Study of factors influencing consumers to adopt EVs," *Business and Economic Research*, vol. 13, no. 2, pp. 1–18, 2023, doi: 10.5296/ber.v13i2.21054.

[7] P. Patil, K. Kazemzadeh, and P. Bansal, "Integration of charging behaviour into infrastructure planning and management of electric vehicles: A systematic review and framework," *Sustainable Cities and Society*, vol. 88, p. 104265, Jan. 2023, doi: 10.1016/j.scs.2022.104265.

[8] P. Fröde, M. Lee, and S. Sahdev. (2023). *Can public EV fast-charging stations be profitable in the United States?, Mckinsey & Company*. [Online]. Available: https://www. mckinsey.com/features/mckinsey-center-for-future -mobility/our-insights/can-public-ev-fast-charging-stations-be-profitable-in-the-united-states (Accessed: 29 October 2023).

[9] A. A. Visaria, A. F. Jensen, M. Thorhauge, and S. E. Mabit, "User preferences for EV charging, pricing schemes, and charging infrastructure," *Transportation Research Part A: Policy and Practice*, vol. 165, pp. 120–143, Dec. 2022, doi: 10.1016/j.tra.2022.08.013.

[10] J. Ma and Q. Yang, *Earth and Environmental Science,* p. 440, 2020, doi: 10.1088/1755-1315/440/3/032078.

[11] M. Pagani, W. Korosec, N. Chokani, and R. S. Abhari, "User behaviour and electric vehicle charging infrastructure: An agent-based model assessment," *Applied Energy*, vol. 254, p. 113680, Nov. 2019, doi: 10.1016/j.apenergy.2019.113680.

[12] S. Kane, N. Manza, F. Nagele, and F. Richter. (2021). *EV fast charging: How to build and sustain competitive differentiation, Mckinsey & Company*. [Online]. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/ev-fast-charging-how -to-build-and-sustain-competitive-differentiation (Accessed: 29 October 2023).

[13] N. Shrestha, "Factor analysis as a tool for survey analysis," American Journal of Applied Mathematics and Statistics, vol. 9, no. 1, pp. 4–11, 2021, doi: 10.12691/ajams-9-1-2.

[14] S. M. Sadiq, S. C. Gansesh, M. Vignesg, V. Madhuri, P. Podugu, and S. N. Ramya, "Empowering the EV Community: A Comprehensive Solution for Electric Vehicle Charging," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 11, no. 8, 2023, doi: 10.17762/ ijritcc.v11i8s.7254.

[15] D. Pevec, J. Babic, A. Carvalho, Y. Ghiassi-Farrokhfal, W. Ketter, and V. Podobnik, "Electric vehicle range anxiety: An obstacle for the personal transportation (r)evolution?," in *Proc. 4th Int. Conf. Smart and Sustainable Technologies (SpliTech)*, Split, Croatia, Jun. 2019, pp. 1–8, doi: 10.23919/SpliTech.2019.8783178.

[16] M. Khaleghikarahrodi and G. A. Macht, "Patterns, no patterns, that is the question: Quantifying users' electric vehicle charging," *Transport Policy*, vol. 141, 2023, doi: 10.1016/j.tranpol.2023.07.020.

[17] Y. Liao, Ç. Tozluoğlu, F. Sprei, S. Yeh, and S. Dhamal, "Impacts of charging behavior on BEV charging infrastructure needs and energy use," *Transportation Research Part D: Transport and Environment*, vol. 116, p. 103645, 2023.

[18] J. Wang, C. Huang, D. He, and R. Tu, "Range anxiety among battery electric vehicle users: Both distance and waiting time matter," 2023, doi: 10.48550/arXiv.2306.05768.

[19] Y. Cao, N. Ahmad, O. Kaiwartya, G. Puturs, and M. Khalid, "Intelligent transportation systems enabled ICT framework for electric vehicle charging in smart city," in *Handbook of Smart Cities: Software Services and Cyber Infrastructure*. Cham, Switzerland: Springer International Publishing, 2018, pp. 311–330.

[20] H. Krishna, K.Jahnavi, and A.Abdulla, "Reservation system for charging electric vehicles," *Sensor*, vol. 22, no. 8, 2022, doi: 10.3390/ s22082834.

[21] R. Basmadjian, B. Kirpes, J. Mrkos, M. Cuchý, and S. Rastegar, "An interoperable reservation system for public electric vehicle charging stations: A case study in Germany," in *Proc. 1st ACM Int. Workshop on Technology Enablers and Innovative Applications for Smart Cities and Communities*, Nov. 2019, pp. 22–29, doi: 10.1145/3364544.3364825.

[22] R. Flocea, A. Hincu, A. Robu, S. Senocico, A. Traciu, M. B. Remus, S. M. Raboaca, and C. Filote, "Electric vehicle smart charging reservation algorithm," *Sensors*, vol. 28, no. 2, 2022, doi: 10.3390/ s22082834.

[23] M. Kam, van der and R. Bekkers, "Comparative analysis of standardized protocols for EV roaming," evRoaming4EU: Realising Cross-Border Charging in Europe, Report D6.1, 2020, doi: 10.13140/RG.2.2.19988. 17283.

[24] M. Kam, van der and R. Bekkers, "Design principles for an "ideal" EV roaming protocol,"

evRoaming4EU Project, Report D6.3, 2020, doi: 10.13140/RG.2.2.13277. 28646.

[25] M. Kam, van der and R. Bekkers, *Achieving Interoperability for EV Roaming: Pathways to Harmonization. Report D6.2 for the evRoaming4EU Project. Rep. Netherlands.* Netherlands: Netherlands Knowledge Platform for Public Charging Infrastructure, 2020, pp. 1–32.

[26] EVroaming Foundation. (2021). *OCPI-2.2.1, EVRoaming Foundation realising cross-border charging.* [Online]. Available: https://evroaming.org/app/uploads/2021/11/OCPI-2.2.1.pdf (Accessed: 29 October 2023).

[27] N. Y. Pehlivan, T. Paksoy, and A. Çalik, Comparison of methods in FAHP with application in supplier selection. *Fuzzy Analytic Hierarchy Process*, pp. 45–76, 2017. doi:10.1201/9781315369884-3.

[28] D.-Y. Chang, "Applications of the extent Analysis Method on fuzzy AHP," *European Journal of Operational Research,* vol. 95, no. 3, pp. 649–655, 1996, doi: 10.1016/0377-2217(95)00300-2.

[29] C. Kahraman, S. Ç. Onar, and B. Öztayşi, "B2C marketplace prioritization using hesitant fuzzy linguistic AHP," *International Journal of Fuzzy Systems,* vol. 20, no. 7, pp. 2202–2215, 2017, doi: 10.1007/s40815-017-0429-4.

[30] C. Kahraman, U. Cebeci, and D.Ruan, "Multi-attribute comparison of catering service companies using Fuzzy AHP: The case of Turkey," *International Journal of Production Economics*, 87(2), pp. 171–184, 2004, doi: 10.1016/s0925-5273(03)00099-9.

[31] F. D. Davis, "A technology acceptance model for empirically testing new end-user information systems: Theory and results," Ph.D. dissertation, Massachusetts Institute of Technology, 1985.

[32] F. D. Davis, P. R. Warshaw, and R. P. Bagozzi, "User acceptance of computer technology: A comparison of two theoretical models," *Management Science,* vol. 35, no. 8, pp. 982–1003, 1989.

[33] R. H. Hoyle, *Handbook of Structural Equation Modelling.* New York, NY: Guilford Press, 2012.

[34] P. S. Malone and J. B. Lubansky, "Preparing Data for Structural Equation Modelling Doing Your Homework," in *Handbook of structural equation modelling.* New York, NY: Guilford Publications, 2012, pp. 263–276.

[35] T. A. Brown, *Confirmatory factor analysis for applied research.* New York, NY: The Guilford Press, 2015.

[36] N. Kock, "Hypothesis testing with confidence intervals and P values in PLS-sem," *International Journal of e-Collaboration,* vol. 12, no. 3, pp. 1–6, 2016, doi: 10.4018/ijec.2016070101.

[37] A. Malkanthie, *Structural Equation Modeling with AMOS.* Panadura, Sri Lanka: Nippon Graphics Pvt. Ltd., 2015, doi: 10.13140/RG.2.1.1960. 4647.

[38] T.A. Whittaker, "A beginner's Guide to Structural Equation Modelling (3rd ed.)," *Structural Equation Modelling: A Multidisciplinary Journal,* vol. 18, no. 4, pp. 694–701, 2011, doi: 10.1080/10705511.2011. 607726.

[39] T. A. Brown. (2015). *Confirmatory factor analysis for applied research.* New York, NY: The Guilford Press.

[40] E. Saad, S. N. Elekyaby, O. E. Ali, and S. F. Hassan, A. E. (2020) 'Double diamond strategy saves time of the design process', *International Design Journal*, 10(3), pp. 211–222, 2020, doi: 10.21608/idj.2020.96345.

[41] S. Das, K. Mitra, and M. Mandal, "Sample size calculation: Basic principles," *Indian J Anaesth.* 2016 Sep, vol. 60, no. 9, pp. 652–656, 2016, doi:10.4103/0019-5049.190621.

[42] D. A., Dillman, J. D. Smyth, and L. M. Christian, *The tailored design method: internet, phone, Mail, and Mixed-mode.* 4th ed. Hoboken, New Jersey: John Wiley & Sons, 2014.

[43] K. A. Batterton and K. N. Hale, "The Likert Scale what it is and how to use it," *Phalanx,* vol. 50, no. 2, pp. 32–39, 2017. [Online]. Available: https://www.jstor.org/stable /10.2307/26296382?seq=1&cid=pdf-reference#references_tab_contents.

[44] L. L. Rademaker, and E. Y. Polush, *Evaluation and Action Research.* London, UK: Oxford University Press, 2022.

[45] H. Noble, and G. Mitchell, "What is grounded theory," *Evid Based Nurs,* vol. 19, no. 2, 2016, doi: 10.1136/eb-2016-102306.

[46] M. S. Rosenbaum, M. L. Otalora, and C. Ram ́ırez, G. ́an, "How to create a realistic customer journey map," *Business Horizons,* p. 1342, 2016, doi: 10.1016/j.bushor.2016.09.01.

[47] E. Merryweather. (2023). *Stories, Epics, Themes and Initiatives for Product Managers, Product School.* [Online]. Available: https://productschool.com/blog/product-fundamentals/stories-epics-themes-initiatives-product-manager (Accessed: 29 October 2023).

[48] P. Parasuraman, L. L. Berry, and V. A. Zeithaml, *Journal of Retailing', SERVQUAL: A multiple- Item Scale for measuring consumer perceptions of service quality,* vol. 64, no. 1, 1988. [Online]. Available: https://www.researchgate. net/publication/225083802_SERVQUAL_A_multiple_Item_Scale_for_measuring_consumer_perceptions_of_service_quality.

[49] G. L. Shostack, (1984) *Designing Services That Deliver, Harvard Business Review.* [Online]. Available: https://hbr.org/ 1984/01/designing-services-that-deliver (Accessed: 29 October 2023).

[50] M. Stickdorn, *This is service design thinking.* Amsterdam, Netherlands: BIS Publishers, 2011.

[51] MEA. (2024). [Online]. https://www.mea.or.th/en/public-relations/corporate-news-activities/announcement /PYHSL54vx, Metropolitan Electricity Authority. [Online]. Available : https://www.mea.or.th/en/public-relations /corporate-news-activities/announcement/PYHSL54vx (Accessed: September 2024).

[52] R. C. Turner and L. Carlson, "Indexes of item-objective congruence for multidimensional items," *International Journal of Testing,* vol. 3, no. 2, pp. 163–171, 2003, doi: 10.1207/s15327574ijt0302_5.

[53] M. Vahedian-Sharoodi, A. Mansourzadeh, S. S. Moghani, and M. Saeidi, "Using the Nominal Group Technique in Group Decision-Making: A Review," *Medical Education Bulletin*, vol. 4, no. 14, pp. 837–845, 2023.

[54] H. F. Kaiser, "An index of Factorial Simplicity," *Psychometrika,* vol. 39, no. 1, pp. 31–36, 1974, doi: 10.1007/bf02291575.

[55] J. Pudpuang and P. Chutima, "Multi-criteria decision making for strategic outsource in semiconductor industry," *2024 6th International Conference on Management Science and Industrial Engineering*, pp. 309–3181, 2024, doi: 10.1145/3664968.3665010

[56] K. Kosanantachai, P. Chutima, and K. Suangpong, "Structural equation model for planning time management of electric buses to utilize and promote tourism services in Bangkok," *2024 6th International Conference on Management Science and Industrial Engineering*, pp. 174–180, 2024, doi:10.1145/3664968.3664990.

[57] S. Pumkrachang, K. Asawarungsaengkul, and P. Chutima, "Design and analysis of the slider shear test system using nested GR&R Measurement System," *Engineering Journal*, 27(3), pp. 11–23, 2023, doi: 10.4186/ej.2023.27.3.11.

[58] C. Kongmunee and P. Chutima, "Analytical Hierarchy Process Approach for improvement of automotive part supplier performance evaluation," *Advanced Science, Engineering and Medicine*, vol. 8, no. 10, pp. 831–835, 2016, doi:10.1166/asem.2016.1941.

Waranthorn Tananuchittikul received a Bachelor of Engineering from Chulalongkorn University Bangkok Thailand. He is a full-time Product Business Development in the EV charging service industry. His research scope of work focus on developing a new conceptual model for interoperability charging practises and service management and design, streamlining EV charging supporting modules to achieve a satisfised customer journey. The work is done by using advanced analytical model and data relationship-based theory

Professor Parames Chutima received a Bachelor of Engineering from Chulalongkorn University, master's degrees from Chulalongkorn University and Asian Institute of Technology, and a PhD in Manufacturing Engineering and Operations Management from the University of Nottingham, UK. He is a full Professor in the Faculty of Engineering at Chulalongkorn University, Thailand, and the Director of the Regional Centre for Manufacturing Systems Engineering, Chulalongkorn University, Thailand. His research interests include multi-objective optimisation in operations management, production planning and control of assembly lines, just-in-time production systems and simulation modelling. He is the author and co-author of many books and scientific articles in prestigious international journals and conferences.