EMall
e-Mobility for All

Requirements Analysis and Specification Document

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Content

1. INTRODUCTION

1.1. Purpose

The continued increase in carbon emissions will cause global warming and sea level rise, producing climate anomalies, increased desertification area, and increased pests and diseases. If the current rate of carbon emissions continues to develop, the global temperature will rise by 2 to 4 degrees in 2050, and the resulting meteorological disasters will damage the ecosystem [1], cause saltwater intrusion, endanger the living environment of human beings and other organisms on earth. Therefore, the reduction of room temperature gas emissions and the reduction of "carbon footprint" should be the consensus of human beings to achieve sustainable development. In 2022, the United Nations Conference on Environment and Sustainable Development will be held in Stockholm with the theme of a healthy planet for the prosperity of all --our responsibility, our opportunity. However, compared with fuel vehicles, electric vehicles still require longer charging time, while the construction of infrastructure such as charging piles is still imperfect. Therefore, reasonable distribution of charging pile resources and intelligent aggregation of charging pile information can greatly facilitate electric vehicle travel and contribute to the popularity of electric vehicles, thus achieving the goal of reducing carbon footprint.

Our goal is to develop a new system eMall -- e-Mobility for All that (i) provides end-users with charging station aggregation query services, preferential information, and charging payment and management functions, as well as intelligent charging planning functions, and (ii) provides Charging Point Operator (CPO) with management and interaction with Distribution System Operator (DSO). The service can optimize the operation process of charging service providers and improve the charging experience of end users.

1.1.1 Goals

Goal	Description
G1	Allow the end user to know about the charging stations nearby, their cost, any special offer they have.

G2	Allow the end user to know book a charge in a specific charging station for a certain timeframe.
G3	Allow the end user to know the charging process at a certain station.
G4	Notify the end user when the charging process is finished.
G5	Allow the end user to know pay for the obtained service.
G6	Suggest the end user go and charge the vehicle, depending on the status of the battery, the schedule of the user, the special offers made available by some CPO, and the availability of charging slots at the identified stations.
G7	Allow the CPO to know the location and “external” status of a charging station (number of charging sockets available, their type such as slow/fast/rapid, their cost, and, if all sockets of a certain type are occupied, the estimated amount of time until the first socket of that type is freed).
G8	Allow the CPO to start charging a vehicle according to the amount of power supplied by the socket and monitor the charging process to infer when the battery is full.
G9	Allow the CPO to know the “internal” status of a charging station (amount of energy available in its batteries, if any, number of vehicles being charged and, for each charging vehicle, amount of power absorbed, and time left to the end of the charge).
G10	Provide the CPO the information acquires by the DSOs about the current price of energy.
G11	Provide the CPO the decision which DSOs to acquire energy (if more than one is available).
G12	Provide the CPO the decision where to get energy for charging (station battery, DSO, or a mix thereof dynamically according to availability and cost).

1.2. Scope:

1.2.1 World Phenomena

Identifier	**Description**
WP1	The end user arranges schedules.
WP2	The end user books a charge in a charging station.
WP3	The end user starts to charge in a charging station.

WP4	The CPO wants to publish a special offer.

1.2.2 Share Phenomena

Identifier	Description
SP1	Updated relative location of the end-user to charging stations.
SP2	The end user’s charging process at a charging station.
SP3	The end user is asked to pay bills for obtained services
SP4	The end user’s battery statue.
SP5	Updated location and “external” status of charging stations (number of charging sockets available, their type such as slow/fast/rapid, their cost, and, if all sockets of a certain type are occupied, the estimated amount of time until the first socket of that type is freed).
SP6	Updated power supply statue.
SP7	Updated charging process of charging stations.
SP8	Updated price and availability of energy from DSO

1.3. Definitions, Acronyms, Abbreviations

1.3.1 Definitions

Definition	Description
End User ID	This is a unique ID generated by eMSPs for the end user.
CPO ID	This is a unique ID generated by CPMS for the CPO.
Charge Station ID	This is a unique ID generated by CPMS for the charge station.

1.3.2 Abbreviations

Abbreviation	Description
RASD	Requirements Analysis and Specification Document
WP	World Phenomena
SP	Shared Phenomena

GX	Goal number X
DX	Domain assumption number X
RX	Requirement number X
eMall	e-Mobility for All
eMSPs	e-Mobility Service Providers
CPMS	Charge Point Management System
CPO	Charging Point Operators
DSOs	Distribution System Operators

4. Revision history

5. Reference Documents

• The specification document “Assignment RDD AY 2022-2023_v2.pdf”

6. Document Structure

This document consists of six parts, as detailed below.

The first part gives the background of the project, as well as the specific objectives of the project and the problems it aims to solve. The scope of the project with shared and world phenomena is given. The relevant Definitions, Abbreviations and descriptions of the project version and overall structure are also given.

The second part gives a general description of the system, including a detailed description of the product perspective, functions, and thus the most important requirements, as well as defining user characteristics, assumptions, dependencies and constraints, and including a class diagram and a state diagram of the software. State diagram.

In the third section, the special requirements of the system are described, providing the design team with more detail than in the second section. This includes functional requirements, non-functional requirements, and requirements for external interfaces. In addition, use case diagrams and sequence diagrams are described.

The fourth section contains a formal analysis performed with Alloy.

The fifth section describes the division of labor and the distribution of work hours among the project members.

The sixth section contains the references used.

2. OVERALL DESCRIPTION

2.1. Product perspective

2.1.1 Scenarios

1. End user search for information about nearby charging stations

When a user needs to use a charging station in a specific location, he can check the nearby charging stations, their costs and services offered through a user-side application such as a web or mobile application. For example, when a user needs to charge his electric vehicle in a certain neighborhood, he can check the charging stations near his current location by checking that charging station A is only 500 meters away and charging station B is 1000 meters away, but the application shows that the cost of A is greater than the cost of B and that B can provide the service preferred by the user such as high power fast charging. The user can choose the most suitable charging station by combining the characteristics of the different charging stations with his current needs.

2. End User books charging services at specific charging stations for a certain period

End users can book charging services at a particular charging station for a certain period, taking into account their schedule and the status of their electric vehicle's battery. For example, a user will charge their car on Tuesday at 3 pm. Until that time, the car’s battery is not empty, and the user has a constant need to use the car. Therefore, the user can reserve a time slot for charging on Tuesday afternoon starting at 3 pm. At the same time, the user must specify a charging station to ensure that the reservation is successful. In this case, he can choose to reserve a charging station near his company or near his home on Tuesday afternoon at 3 pm, depending on his schedule.

3. Report to the end user when the charging process starts

When an end-user connects his electric vehicle to a charging socket and starts the charging process, he will receive a message to confirm the start of the charging process. For example, a charging station has a socket that is damaged and cannot provide a normal charging service. When the user's electric vehicle is connected to this socket, he will not receive any indication. Therefore, he can be sure that he will not be able to use this socket. When he uses another socket, he can receive an alert that the charging process is starting.

4. The terminal notifies the user when the charging process is complete

After the user's electric vehicle is fully charged, a terminal such as a mobile application, SMS or web page will send a notification to the user that the charging process of his electric vehicle is finished, reminding him to retrieve his vehicle as soon as possible, freeing up the free socket and avoiding damage to his vehicle. Charging sockets are valuable resources for charging stations and are related to the service rate and throughput of the charging station. When a fully charged electric vehicle continues to occupy a charging socket it is undoubtedly a waste of resources. In addition to this, the purpose of sending this notification is to inform the user of the location of their vehicle and to avoid damage to their electric vehicle if it is left unattended for a long period of time.

5. The end user pays for the service.

In practice, end users may use different services. For example, fast charging socket, some offers, etc. Therefore, our application side should inform the end-user of the expected spend before he starts charging his electric vehicle and remind him to pay after he finishes charging. For example, if a user books and uses a fast charging socket service for two hours, the price for that service is 2 euros per hour. At the same time, the user selects a one-euro discount offer. Then, before charging starts, the application should inform the user that the total price of the service booked is 3 euros and ask for payment after the user finishes charging.

6. Advise end users to charge their electric vehicles

The eMSP monitors the battery status of the electric vehicle against the user's schedule and interacts with the CPO to determine an appropriate time to suggest that the end user charge the electric vehicle at a particular charging station. This depends on the remaining battery charge, the user's availability, the number of available outlets at a given charging station, and the special offer from the CPO. For example, based on the end user's schedule, he will have free time at 5:00 p.m. on Thursday and the battery level is expected to be below a threshold of, say, twenty percent at that time. By looking up nearby charging stations and combining them with the offers made by the CPO, the application should alert the end user to charge at that free time and make a recommendation on which charging station to charge at.

7. CPO can monitor the location and "external" status of a charging station

The CPO logs into the application using their unique credentials. They select the charging station they want to monitor from a list of available stations in their network. The CPMS displays the location of the selected charging station on a map, along with real-time information about the station's external status (e.g., availability, current usage, and any potential issues or maintenance needs). The CPO can use this information to make informed decisions about how to manage the charging station, such as redirecting users to other stations if the selected one is unavailable, or scheduling maintenance if necessary. The CPO can also use the CPMS to monitor multiple charging stations simultaneously, allowing them to manage their entire network of charging stations quickly and easily from a single interface.

8. CPO easily monitor and manage the charging process of a vehicle

End users check the status of the charging socket to ensure that it is available for use. Then they scan the QR code on the vehicle's charging port or enter the vehicle's identification number to start the charging process. The CPMS would then need to determine the maximum amount of power that the vehicle can accept and compare it to the power output of the socket. Once this information has been determined, the CPO can select the appropriate socket on the charging station. When the battery is full, the CPMS will notify the CPO and the charging process will automatically stop. The CPO can then check the charging logs and billing details through the CPMS to track the usage and cost of the charging process.

9. CPO can monitor and manage "internal" status of a charging station

The CPO logs into the CPMS and selects the charging station they want to check the status of. The system displays the current status of the charging station, including the number of available charging ports, the status of each port (e.g., charging, available, or reserved), and any relevant information such as the charging rate or estimated time to full charge. The CPO can view detailed information about each charging port, including the make and model of the vehicle currently charging, the charging rate, and the estimated time to full charge. The CPO can also view a history of charging events at the station, including the duration of each charge, the vehicle makes and model, and any relevant notes or comments. If there are any issues with the charging station, such as a malfunctioning port or a power outage, the CPO can use the system to troubleshoot and resolve the issue. The CPO can also use the system to update the status of the charging station, including adding or removing charging ports, changing charging rates, or modifying the availability of each port. The system automatically updates the status of the charging station in real time, allowing CPOs to always have up-to-date information on the internal status of the charging station.

10. CPO acquire information from DSOs about the current price of energy

The CPO logs into the CPMS and selects the option to view the current energy prices. The system displays a list of available DSOs and their corresponding prices. The CPO selects the DSO they are interested in, and the application displays the current price of energy offered by that DSO. The CPO can compare the prices of different DSOs and make an informed decision on which one to use for their charging station. The CPO can also view historical data on energy prices to see trends and make predictions on future prices. The system automatically updates the prices offered by the DSOs in real-time, allowing the CPO to always have the most up-to-date information. The CPO can also use the system to set alerts for when energy prices reach a certain level, allowing them to take advantage of favorable prices and save on their energy costs.

11. Provide the CPO the decision which DSOs to acquire energy

The CPO can use the CPMS to monitor the real-time energy availability and pricing from different DSOs. The CPMS can also track the CPO's energy usage and budget, as well as any regulatory requirements and incentives. Based on this information, the CPMS can generate a recommendation for the CPO on which DSO to choose for acquiring energy. For instance, the CPMS may suggest selecting a DSO with the lowest price and sufficient energy availability to meet the CPO's needs. The CPO can then review and approve the recommendation before proceeding with the energy acquisition. In addition, the CPMS can provide ongoing monitoring and optimization of the energy acquisition process. For example, it can alert the CPO if there are changes in energy availability or pricing from the selected DSO and provide updated recommendations accordingly. This can help the CPO make informed and cost-effective decisions on energy acquisition, while also ensuring compliance with regulatory requirements.

12. Provide the CPO the decision where to get energy for charging dynamically

The CPMS might monitor the current battery levels and charging rates of the station battery, as well as the current energy prices from the DSO. Based on this information, the CPMS could make a recommendation to the CPO on the optimal source of energy for charging. For example, if the station battery is low and the DSO energy prices are high, the CPMS might recommend that the CPO use a mix of energy from both sources to minimize costs and ensure a steady supply of energy. Alternatively, if the station battery is full and the DSO energy prices are low, the CPMS might recommend that the CPO only use energy from the DSO to maximize cost savings. By using a Charge Point Management System, the CPO can make informed decisions on where to get energy for charging, based on real-time data and analysis provided by the system.

2.1.2 Class diagram

This is the class diagram, where the information about DSO is provided by a third party and obtained by the API interface. At the same time, the eMall system will be structured with two subsystems: end user-oriented eMSP and CPO-oriented CPMS. However, for the sake of scalability, the eMSP system can also access the CPMS systems of other third-party organizations, in which case the CPO class can also be replaced by the corresponding API.

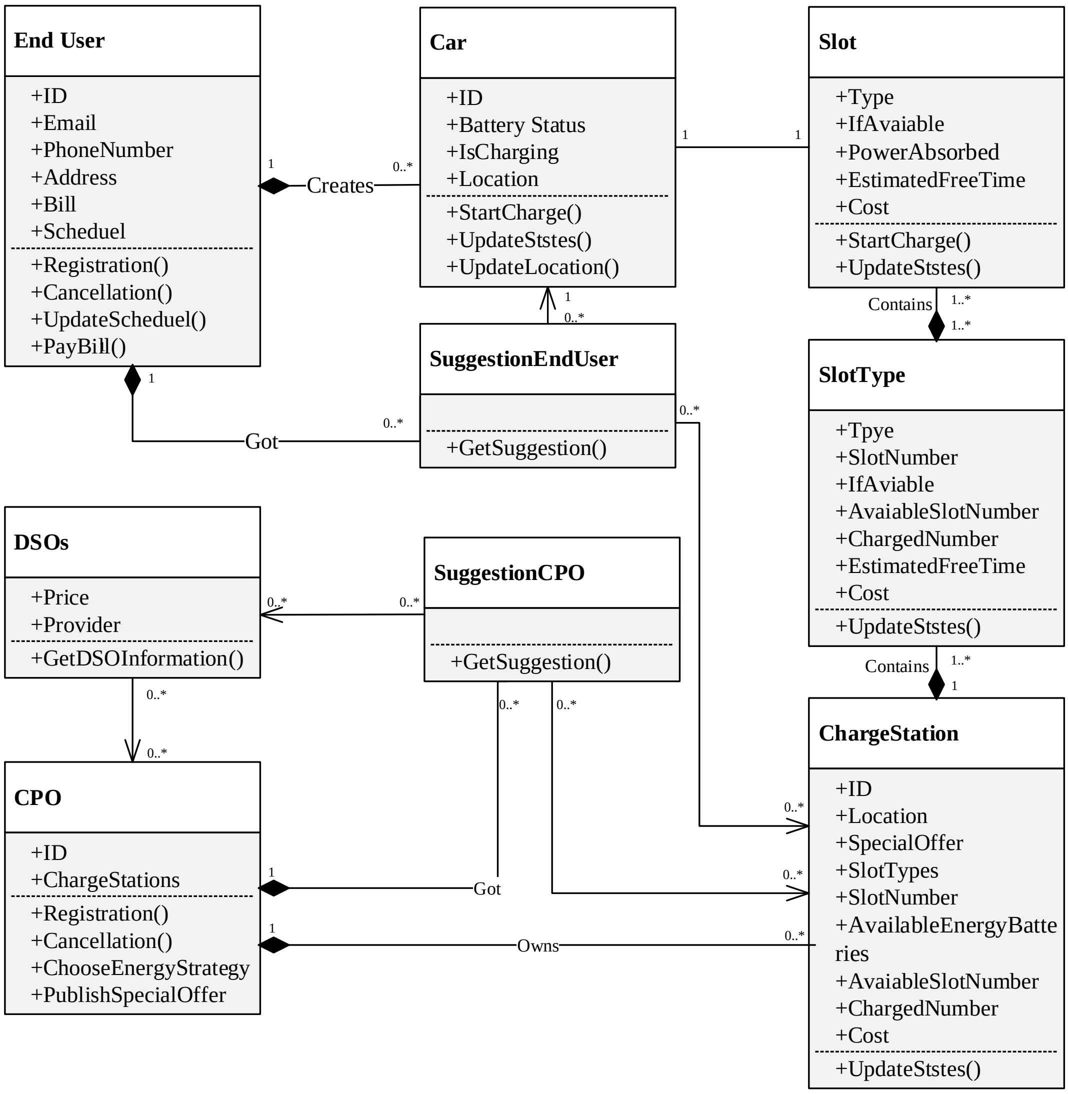


Figure 2-1-1 Class Diagram of eMall

2.1.3 State charts

As mentioned in the previous section, this document treats eMSP and CPMS as two separate systems that communicate with each other through APIs and have different user access interfaces.

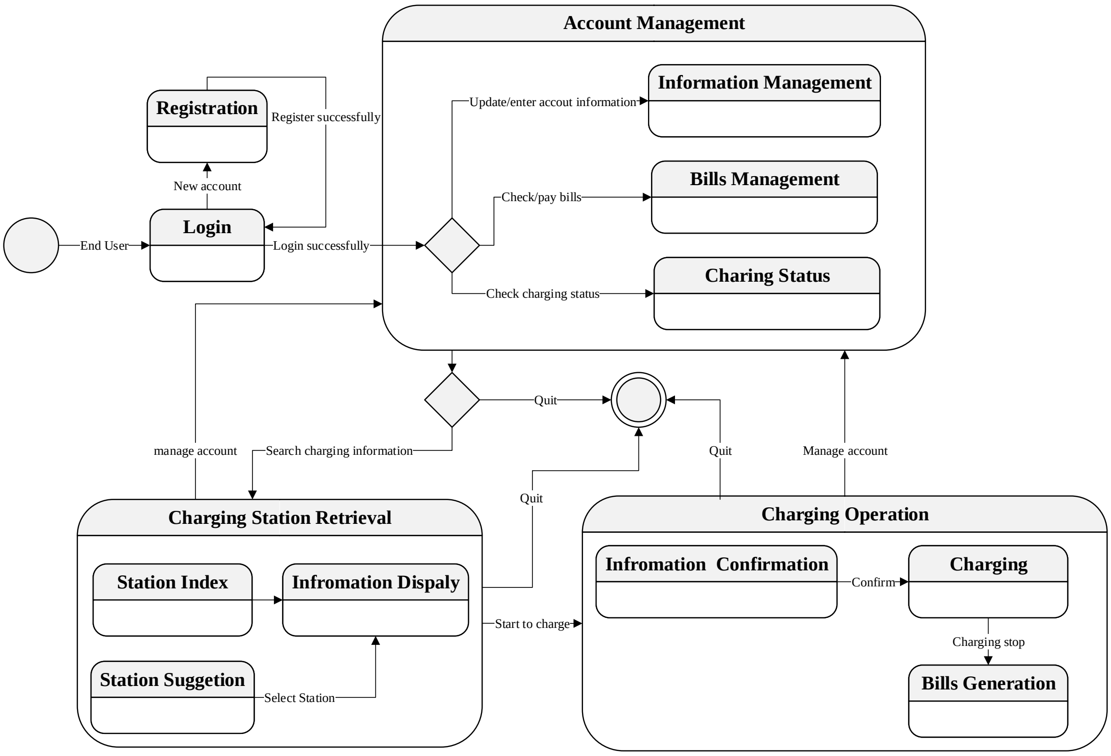


Figure 2-1-2 State Chart of eMSPl

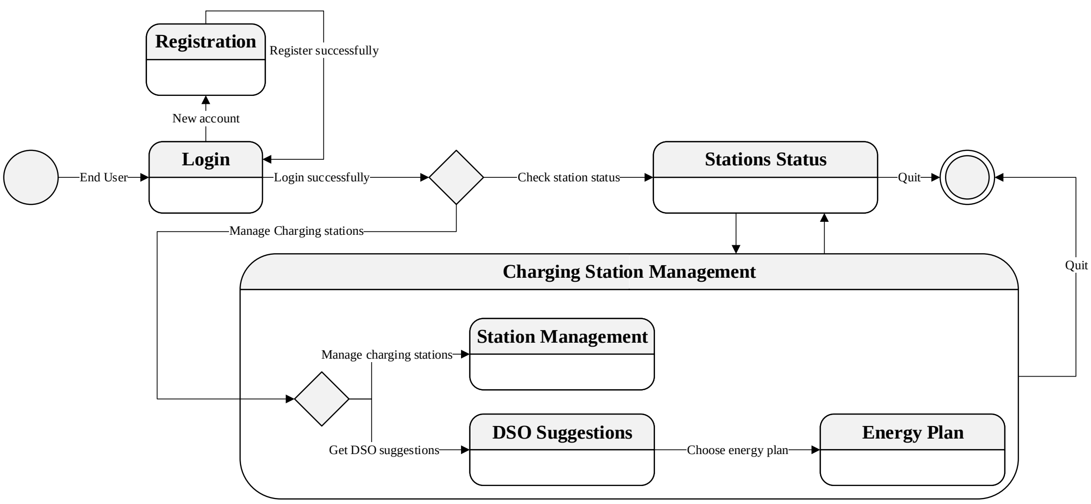


Figure 2-1-3 State Chart of CPMS

2.2 Product functions

2.2.1 End-users easily find, book, and pay for charging services

The eMSP allows users to easily discover and locate charging stations near their current location or a specific destination. They can browse through a list of available charging stations, view their features and pricing, and book a charging session in advance or on-demand.

Once a charging session is booked, users can track the status of their charging session and receive notifications when their vehicle is fully charged. They can also easily pay for the charging services using a variety of payment options such as credit card, mobile wallet, or e-wallet.

Additionally, the functionality provides users with a comprehensive overview of their charging history and the ability to manage their charging preferences and preferences. This allows them to optimize their charging sessions and save money on their electric vehicle charging expenses.

2.2.2 Intelligent charging planning for end-users

This functionality will provide a comprehensive and convenient solution for the end user to charge their electric vehicle. Depending on the status of the battery, the eMSP will suggest charging stations that are nearby and have the necessary charging capabilities for the user's vehicle.

And then, the eMSP takes into account the user's schedule and provides suggestions for charging stations that are available at the desired time. This ensures that the user can easily find a charging station that fits their schedule and allows them to charge their vehicle without any inconvenience. Also, the special offers made available by some CPO will be provided to the user. This allows the user to take advantage of any discounted charging rates or other promotions that may be available at the suggested charging stations.

Checking the availability of charging slots is also important. The eMSP will automatically suggest charging stations that have open slots. This ensures that the user can easily find a charging station that has the capacity to charge their vehicle without having to wait in line or search for an alternative charging station.

2.2.3 Monitoring and control of charging stations

One of the most important aspects of the CPMS is to allow the CPO to monitor the status and usage of each charging station in real time. This includes tracking the availability of charging sockets, the amount of energy being delivered to each vehicle, and the duration of each charging session. Real-time monitoring of station status allows a CPO to track the status of their charging stations in real-time, such as charging current, voltage, and power output. This data can be used to estimate when the first socket will be released if all sockets of a certain type are full. Additionally, this data can be used to identify any potential issues with the charging station that need to be addressed.

The CPMS also allows the CPO to monitor station performance. This includes generating reports on the usage and performance of the station, such as the amount of energy available in the battery, if any, the number of vehicles being charged, and the amount of power absorbed by each charging vehicle and the time remaining before charging ends. This data can be used to identify any issues with the station or to analyze the performance of the station over time.

Additionally, remote control of charging stations is allowed, including the ability to start and stop charging sessions and infer when the battery is full.

2.2.4 Optimize costs and reduce environmental impact

The CPMS gathers and analyzes data on the available energy sources and the prices offered by different DSOs. This includes information on the type of energy source, the amount of energy available, the location of the source, and the price per unit of energy. This data is used to calculate the most cost-effective options for acquiring energy and to determine the type of energy combination. This may involve considering factors such as the availability of renewable energy sources, the proximity of the charging station to the vehicles, and the potential savings from using lower-cost energy sources.

The system presents the CPO with a list of suggested DSOs and charging locations, along with the estimated costs and potential savings. The CPO can then review the suggestions and select the options that best fit their needs and budget.

The system also provides ongoing monitoring and updates on the energy prices and availability, allowing the CPO to adjust their energy acquisition and charging strategies as needed.

2.3. User characteristics

End users are individuals who use the eMSP to access charging services for their electric vehicles. They may use the eMSP to search for charging stations, book a charge, start the charging process, monitor the charging progress, and pay for the charging services.

CPOs are organizations that own and manage charging stations. They use CPMS to manage the charging process at their charging stations, including viewing the status of the charging stations, initiating the charging process for a vehicle, monitoring the charging progress, and deciding which DSO to acquire energy from and where to get energy for charging.

2.4. Assumptions, dependencies and constraints

Identifier	**Description**
D1	End users have a device (e.g. smartphone) with internet connectivity and GPS capabilities, which allows them to access information about charging stations and locate nearby stations.
D2	End users are able to use a web browser or mobile app to access the system and view information about charging stations, book a charge, and pay for the service.
D3	Charging stations have the necessary hardware and infrastructure (e.g. charging sockets) to support the charging of electric vehicles.
D4	Charging stations have the necessary software (e.g. CPMS) to manage the charging process and communicate with eMSPs and DSOs.
D5	CPOs have the necessary infrastructure (e.g. batteries, energy management systems) to support the storage and distribution of energy to charging vehicles.
D6	The eMSP is able to communicate with multiple CPMS, and the CPMS can communicate with multiple DSOs, and facilitate the interaction between them through uniform APIs.
D7	The eMSP is able to handle multiple users concurrently and maintain the privacy and security of each user's data.
D8	The eMSP is able to suggest charging options to end users based on the status of their vehicle's battery, their schedule, and the availability and cost of charging stations.
D9	The CPMS is able to accurately track and report the charging process to CPO, including the status of battery of charge station current, which DSO the end user uses, and any errors or issues that may occur.

D10	The CPMS can report the charging process to the eMSP, including the amount of energy consumed, the time remaining until the charge is complete, and any errors or issues that may occur. The eMSP will report this information to the end user in parallel.
D11	The eMSP can manage bills of end users.
D12	The eMSP can provide bill data for a specific time period to the CPMS and can show charging station revenue and remittance to the CPO.
D13	CPOs are able to set the cost of charging based on the current price of energy from DSOs and/or the availability of energy in the station's batteries.

3. SPECIFIC REQUIREMENTS

3.1 External Interface Requirements

3.1.1 User Interfaces

The user interface of eMall should be easy to use and intuitive, suitable for users of all skill levels. Additionally, the interface should be responsive and able to handle multiple users simultaneously. It should also be compatible with different devices, such as smartphones, tablets, and desktop computers, to ensure that end-users and CPO can access the system from any device.

3.1.2 Hardware Interfaces

The system typically requires an Ethernet connection to communicate with other devices and the internet. This can be through a wired Ethernet connection or through Wi-Fi. Charging stations may include various sensors, such as temperature sensors, current sensors and voltage sensors, to collect data. This data can be used to optimize charging services and improve efficiency. However, it is assumed that the sensors are managed externally and that an API is provided to retrieve the data. The system should also have a hardware interface for connecting to security systems, such as cameras or alarms, to ensure the safety and security of the charging stations and users.

3.1.3 Communication Interfaces

The eMall would depend on the specific requirements of the system. However, some potential requirements could include:

Data transfer: The system would likely need to be able to transfer data between the charging service and the charge points, such as information about available charging stations, charging rates, and energy usage.

Control and monitoring: The system would need to be able to control and monitor the charging process at each charge point, including starting and stopping charging, adjusting charging rates, and monitoring energy usage.

Security: The system would need to have robust security measures in place to protect against unauthorized access or tampering with the charging service and charge points.

Network connectivity: The system would likely need to have some form of network connectivity, such as through Wi-Fi or cellular data, to allow for communication between eMSPs and charge points.

3.2. Functional Requirements

3.2.1 Use Cases

1. End user registration and verification

Actor	**End user**
Enter conditions	The end user does not have an account.
Event Flow	End user fills in personal information. End user confirms identity verification (via SMS or email). eMSP returns the registration success notification.
Exit Conditions	The end user registers successfully.
Exceptions	The end user has not filled out all the mandatory information. The email or phone number is already bound to the user. The verification code is not filled in correctly.

2. End user logins

Actor	**End user**
Enter conditions	The end user has an account and is not logged in yet.
Event Flow	End user fills in email or phone number and password. eMSP returns the login success notification.

Exit Conditions	The end user logins successfully.
Exceptions	The end user entered wrong password. The email or phone number is not bound to any existing account.

3. End user manages account information

Actor	End user
Enter conditions	The end user has an account with the eMSP
Event Flow	The end user selects the option to manage their account information. eMSP displays the current personal information, vehicle information, cell phone and email binding status of the end user's account, and the access schedule and phone location information permission status. The end user enters or updates any of the personal, vehicle, or cell phone and email binding information. The Users can also authorize eMSP to bind their own schedule (calendar app, such as Google calendar or Apple calendar), location information, and vehicle battery status to make charging post suggestions smarter. The end user confirms the updated information. eMSP updates the end user's account with the new information and sends a notification to the end user to confirm the update.
Exit Conditions	The end user has successfully updated their account information.
Exceptions	If the end user attempts to update the information with invalid or incomplete data, the app displays an error message, and the end user must correct the information before continuing.

4. End user searches or gets suggestion for charging slots

Actor	End user
Enter conditions	The end user has installed the eMSP on their device and has logged. The end user's device has a connection to the internet.
Event Flow	The end user selects the "Find Charging Slot" option. eMSP prompts the end user to enter their current location and the desired charging type (slow, fast, or rapid).

	eMSP application searches for available charging slots at nearby charging stations based on the end user's location and desired charging type. If the end user has opted in to receive proactive charging suggestions and authorize the relevant information, the eMSP application may also suggest a charging slot based on the end user's battery level, schedule, and special offers from CPOs. The eMSP application displays a list of available charging slots to the end user, including information such as the charging station location, cost, and availability.
Exit Conditions	The end user finished finding charging slots.
Exceptions	If no charging slots are available at nearby charging stations, the eMSP application will display a notification to the end user indicating that no charging slots are currently available. If the end user's device is not connected to the internet, the eMSP application will not be able to search for or suggest charging slots.

5. End user books a charge slot.

Actor	**End user**
Enter conditions	The end user has installed the eMSP on their device and has logged. The end user's device has a connection to the internet.
Event Flow	The end user selects a charging slot from the list which obtained in the previous table and confirms the booking. The eMSP application confirms the booking and displays a notification to the end user. The end user can view or chancel their booked charging slot in eMSP.
Exit Conditions	The end user has successfully booked a charging slot.
Exceptions	If no charging slots are available at nearby charging stations, the eMSP application will display a notification to the end user indicating that no charging slots are currently available.

6. End user charges vehicles and gets to know charging process.

Actor	**End user**
Enter conditions	The end user has installed the eMSP on their device and has logged.

	The end user's device has a connection to the internet. The end user has booked a charging slot at a charging station and has arrived at the station.
Event Flow	The end user selects the "Charge Vehicle" option and inserts the plug into the vehicle. The eMSP prompts the end user to confirm the charging slot that they have booked. The end user confirms the booking and initiates the charging process. The eMSP communicates with the charging station's CPMS to start the charging process. The charging process begins and the eMSP application displays a notification to the end user indicating that charging has started. The end user can monitor the charging process through the eMSP application, including the amount of power being absorbed and the time remaining until the charging process is complete. When the charging process is complete, the eMSP application sends a notification to the end user and stops the charging process. The eMSP application generates a bill for the charging service based on the cost of the charging slot and the duration of the charging process.
Exit Conditions	The end user has successfully charged their vehicle.
Exceptions	If there are any issues with the charging station or the charging process, eMSP will display a notification to the end user indicating the issue and providing instructions on how to resolve it. If end user has not completed payment for previous order, eMPS will prompt the user to pay first before proceeding to the next charge.

7. End user manages bills.

Actor	**End user**
Enter conditions	The end user has charged their vehicle at a charging station and has received a bill for the charging service.
Event Flow	The end user selects the "Manage Bills" option from the main menu.

	The eMSP application displays a list of the end user's past and current bills. The end user selects a bill from the list to view the details. The eMSP application displays the bill details, including the charging station location, cost, and duration of the charging process. The end user can choose to pay the bill through the eMSP application using a preferred payment method. The eMSP application confirms the payment and updates the bill status to "paid".
Exit Conditions	The end user has successfully managed their bills and completed the payment process.
Exceptions	If there are any issues with the payment process, the eMSP application will display a notification to the end user indicating the issue and providing instructions on how to resolve it.

8. CPO monitors charging stations.

Actor	**CPO**
Enter conditions	The CPO has logged in to the CPMS.
Event Flow	The CPMS displays a list of all charging stations under the CPO's management. The CPO selects a charging station from the list to view the current state of that station or get a overview of all stations. The CPMS displays the external state of the selected station, including the number of charging sockets available, their type, their cost, and the estimated time until the first socket of each type is. The CPMS also displays the internal state of the selected station, including the amount of energy available in its batteries the number of vehicles being charged, and the amount of power absorbed, and time left to the end of the charge for each charging vehicle.
Exit Conditions	The CPO has successfully viewed the current state of the selected charging station.
Exceptions	If there are any issues with the CPMS or the charging station, the CPO may not be able to view the current state of the station.

9. CPO manages charging stations.

Actor	**CPO**
Enter conditions	The CPO has logged in to the CPMS and selected a charging station.
Event Flow	The CPO can choose to make changes to the charging station, such as adjusting the cost of the charging sockets, turning off certain sockets, or provides special offers. The CPMS updates the charging station based on the changes
Exit Conditions	The CPO has successfully managed the selected charging station.
Exceptions	If there are any issues with the CPMS or the charging station, the CPO may not be able to make changes to the station.

10. CPO chooses an energy solution for charging

Actor	**CPO**
Enter conditions	The CPO has logged in to the CPMS and selected a charging station.
Event Flow	The CPMS displays a list of DSOs, including price, and availability. The CPMS displays the current energy solution for the selected charging station, which could be station battery, DSO, or a mix thereof. The CPMS displays a list of suggested energy solutions, including the estimated cost and potential impact on the charging process. The CPO can choose to select one of the suggested solutions, or manually input their own energy solution. The CPMS updates the energy solution for the selected charging station based on the CPO's choice.
Exit Conditions	The CPO has successfully chosen an energy solution for the selected charging station.
Exceptions	If there are any issues with the CPMS or the charging station, the CPO may not be able to set up an energy solution.

3.2.2 Use case diagrams

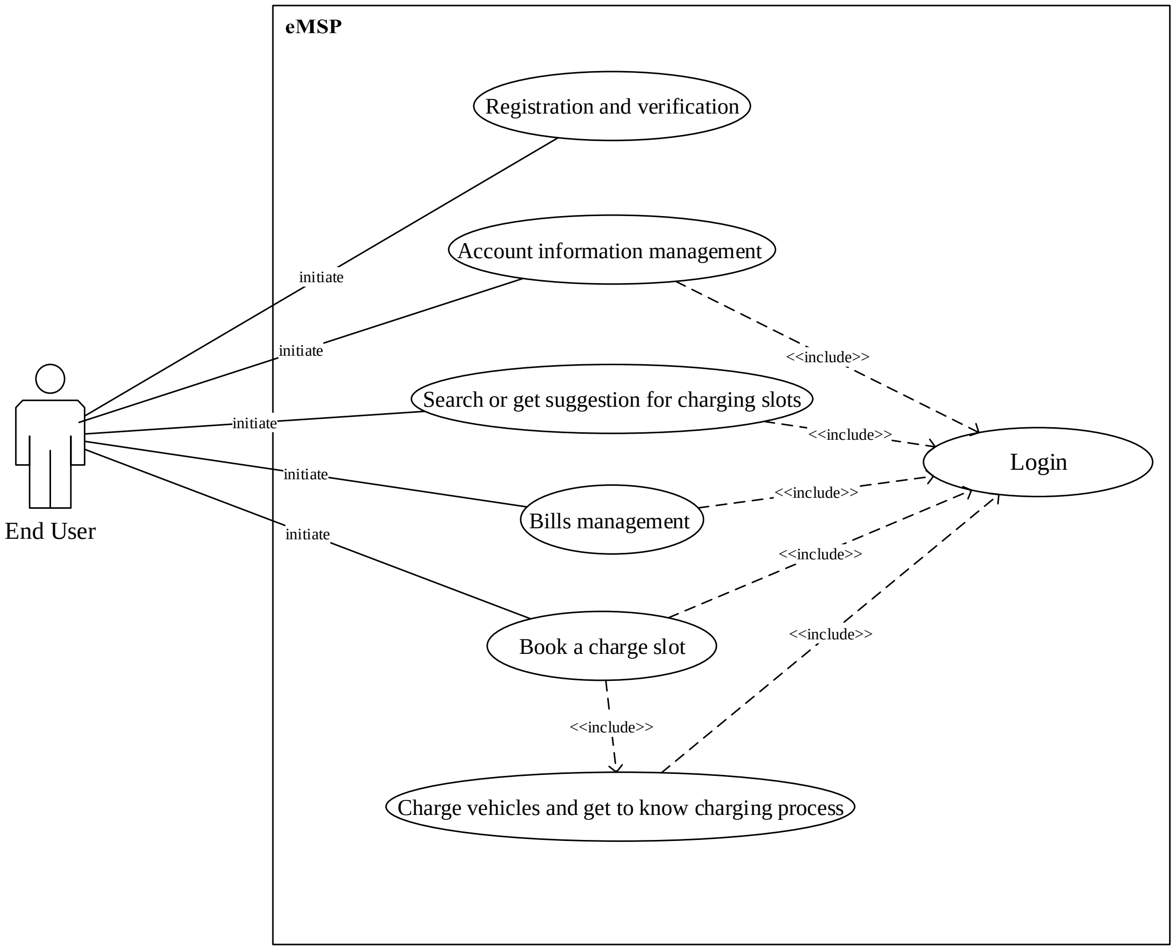


Figure 3-2-1 Use case diagram for a end user

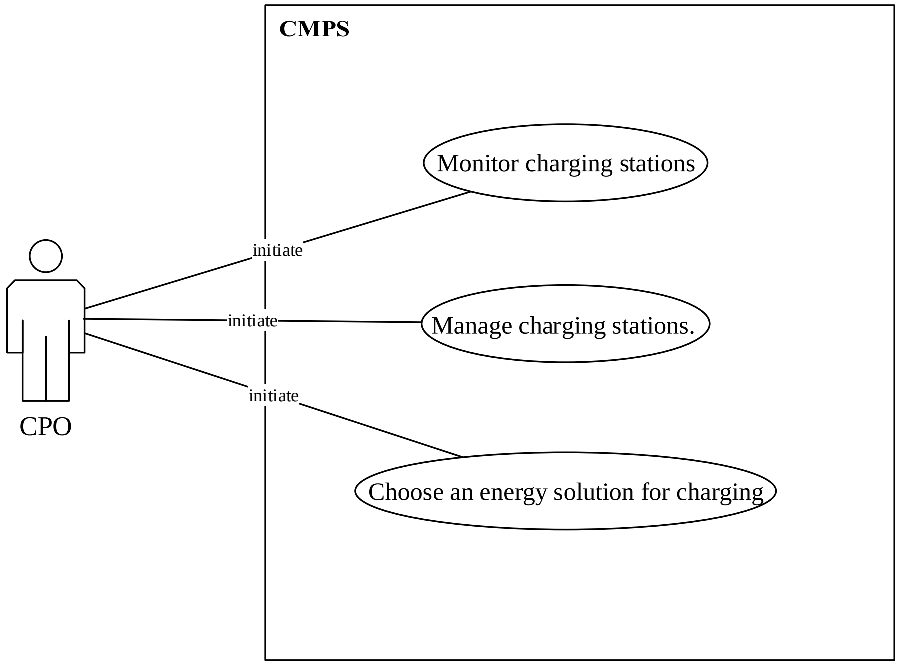


Figure 3-2-2 Use case diagram for CPO

3.2.4 Sequence diagrams

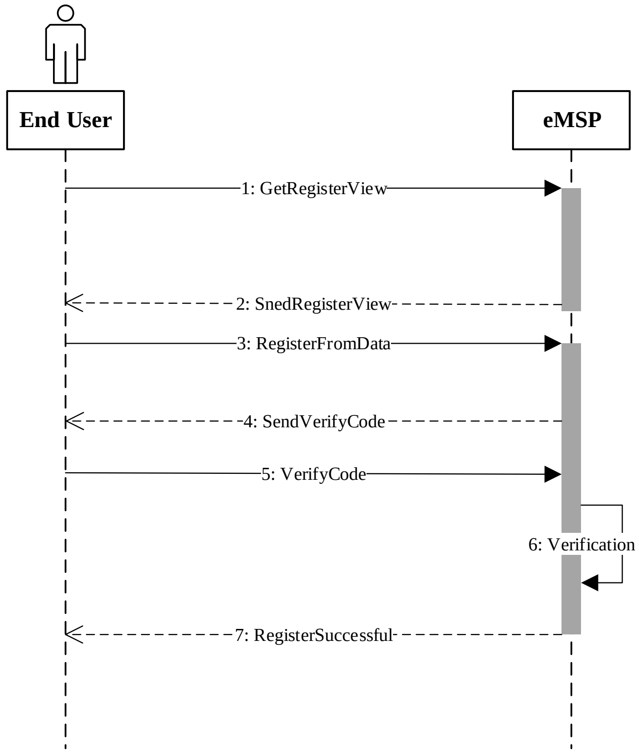


Figure 3-2-3 Sequence diagrams of "Registration and verification"

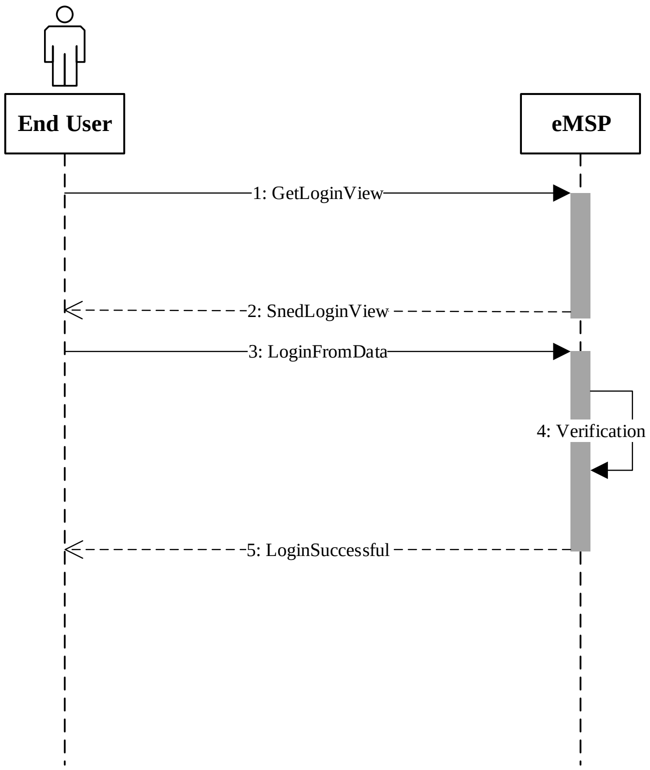


Figure 3-2-4 Sequence diagrams of "Login"

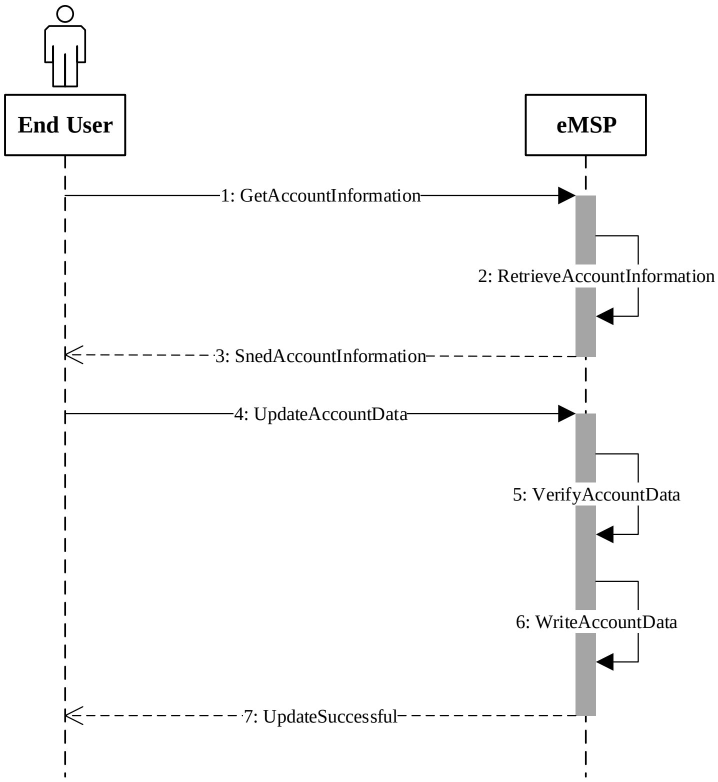


Figure 3-2-5 Sequence diagrams of "Account information management"

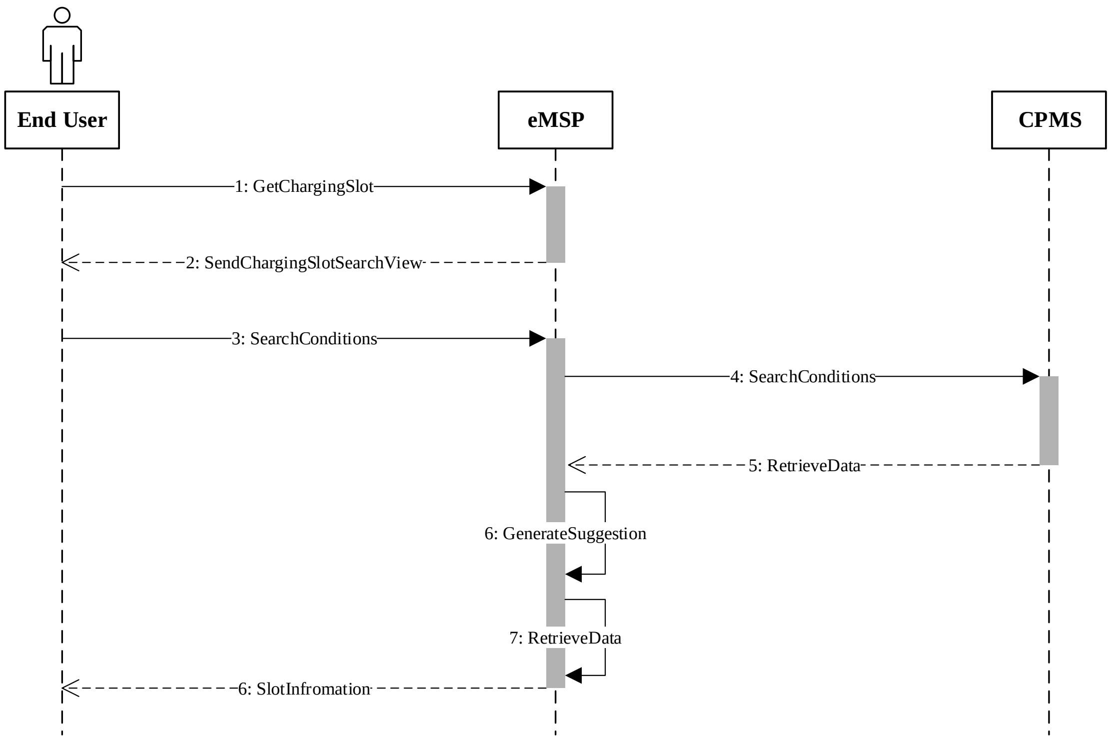


Figure 3-2-6 Sequence diagrams of "Search or get suggestion for charging slots"

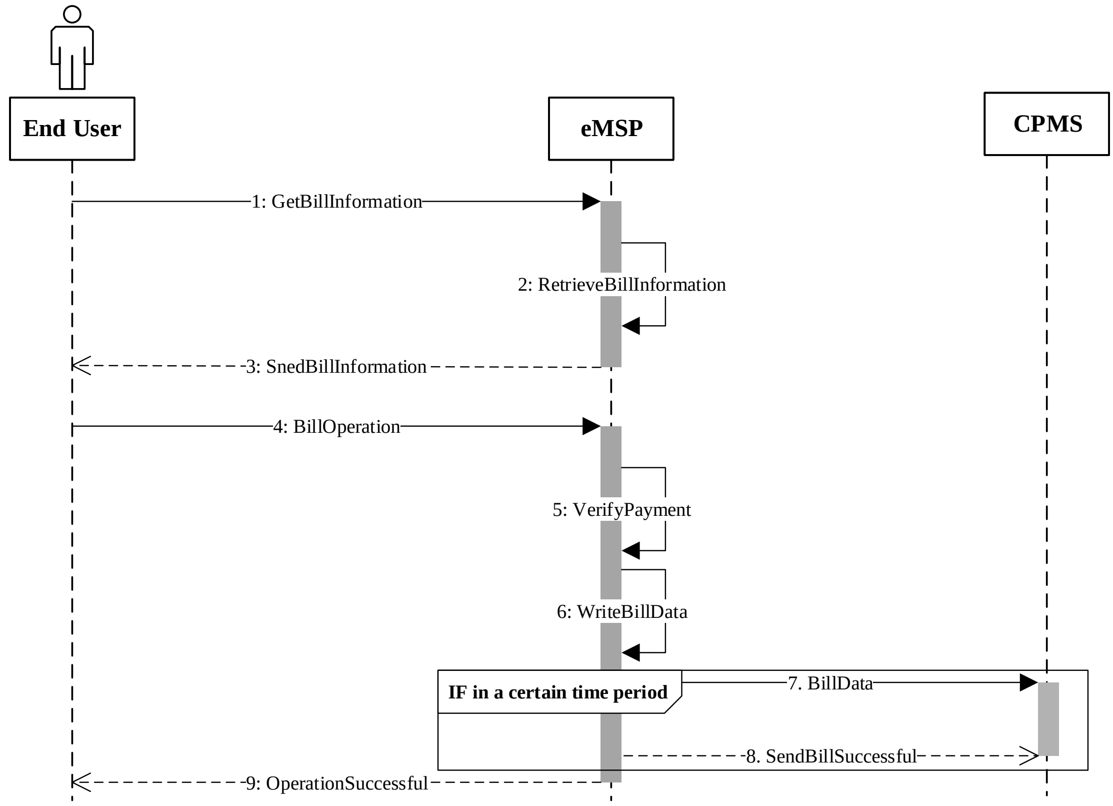


Figure 3-2-7 Sequence diagrams of "Bills management"

The billing data between the eMSP and CPMS is communicated asynchronously. That is, the eMSP acts as an "intermediary", handling the manassgement of end-user payment information, as well as validating and storing user payments. The eMSP will aggregate the revenue of the charging station within a certain time period and send the relevant data and payments to the CPMS.

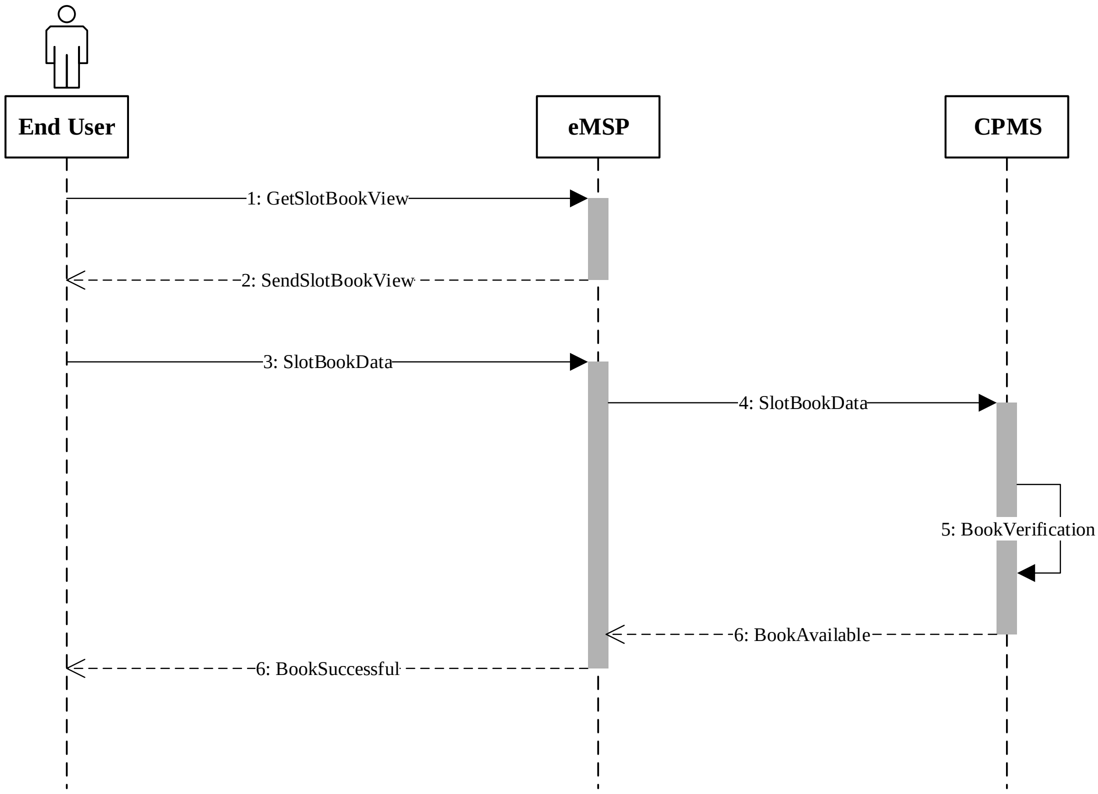


Figure 3-2-8 Sequence diagrams of "Book a charge slot"

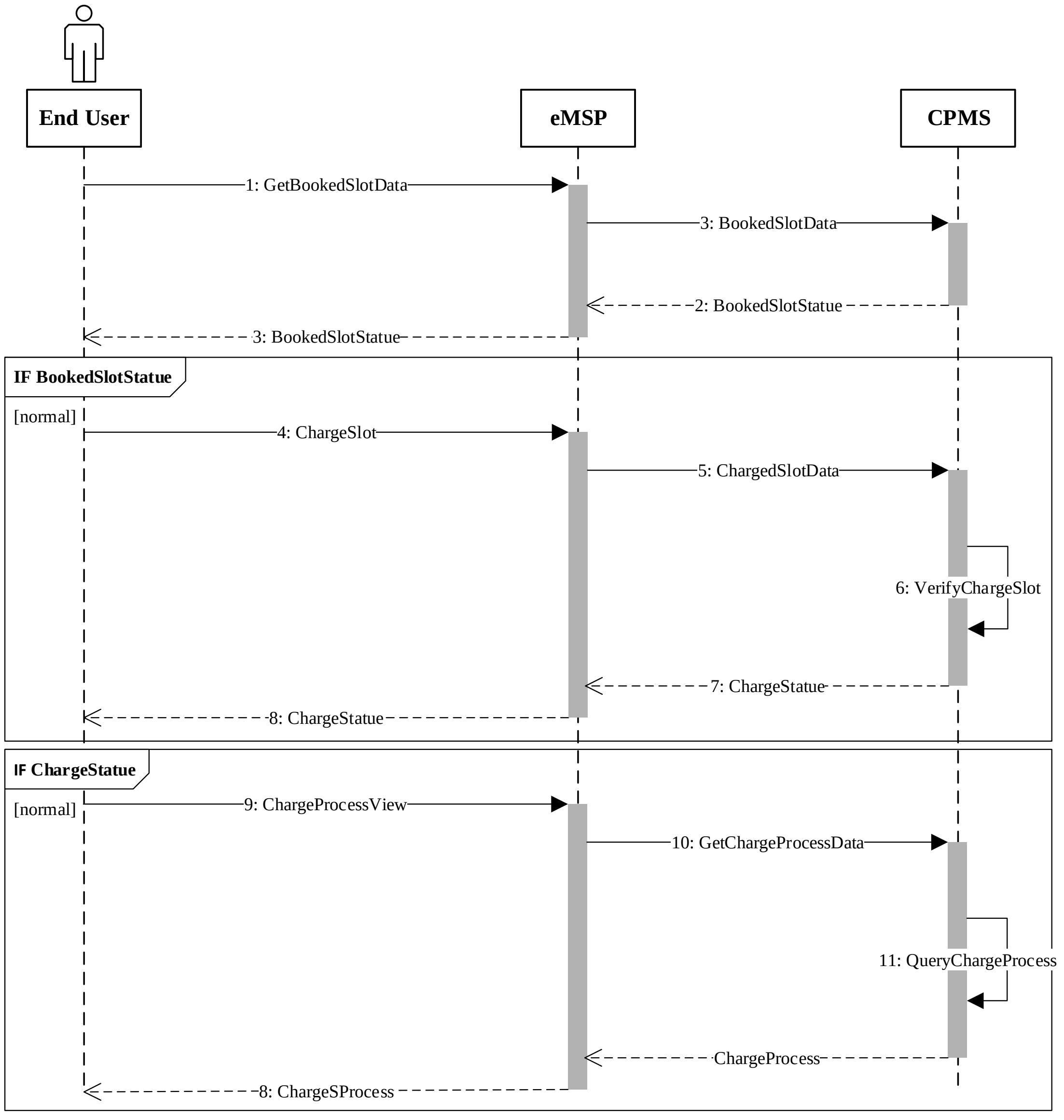


Figure 3-2-9 Sequence diagrams of "Charge vehicles and get to know charging process"

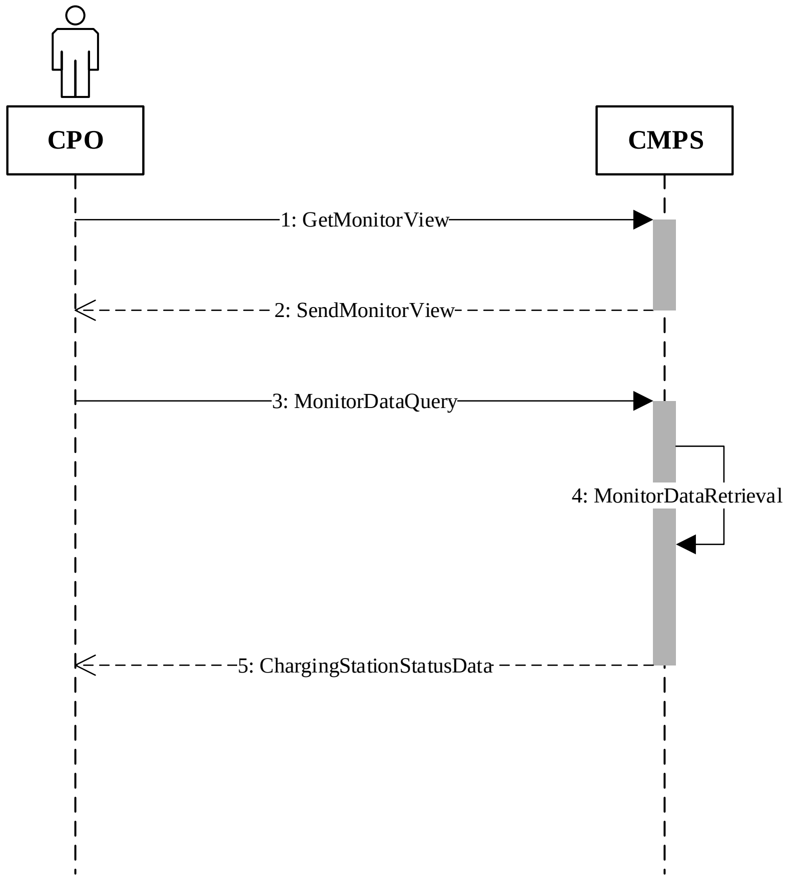


Figure 3-2-10 Sequence diagrams of "CPO monitor charging stations"

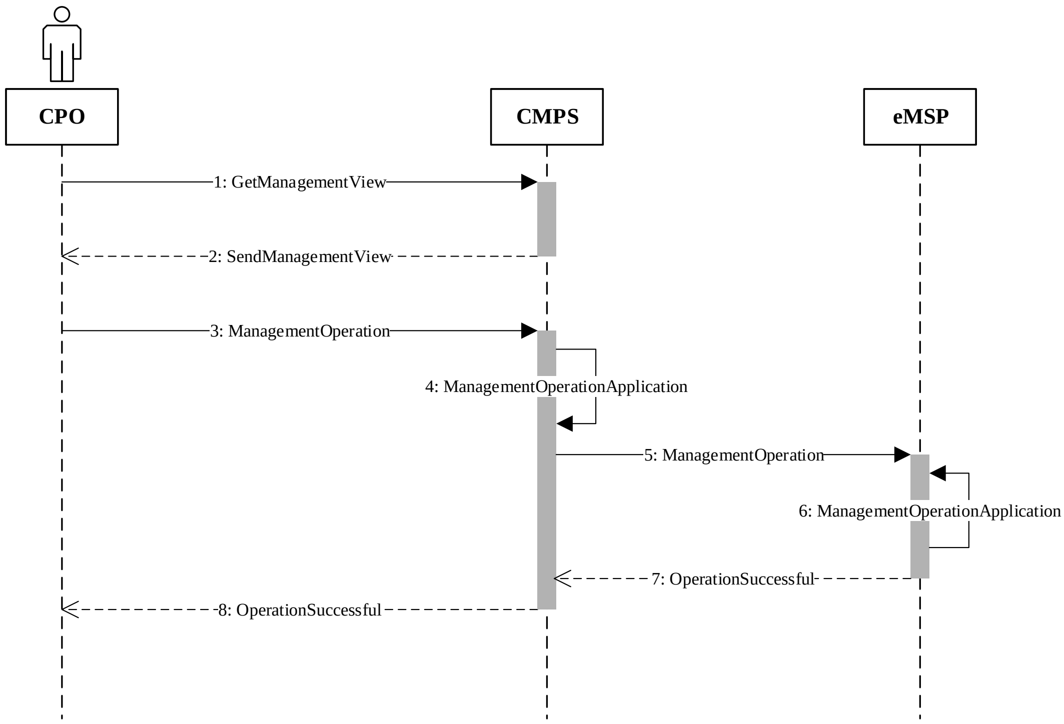


Figure 3-2-11 Sequence diagrams of "CPO manages charging stations."

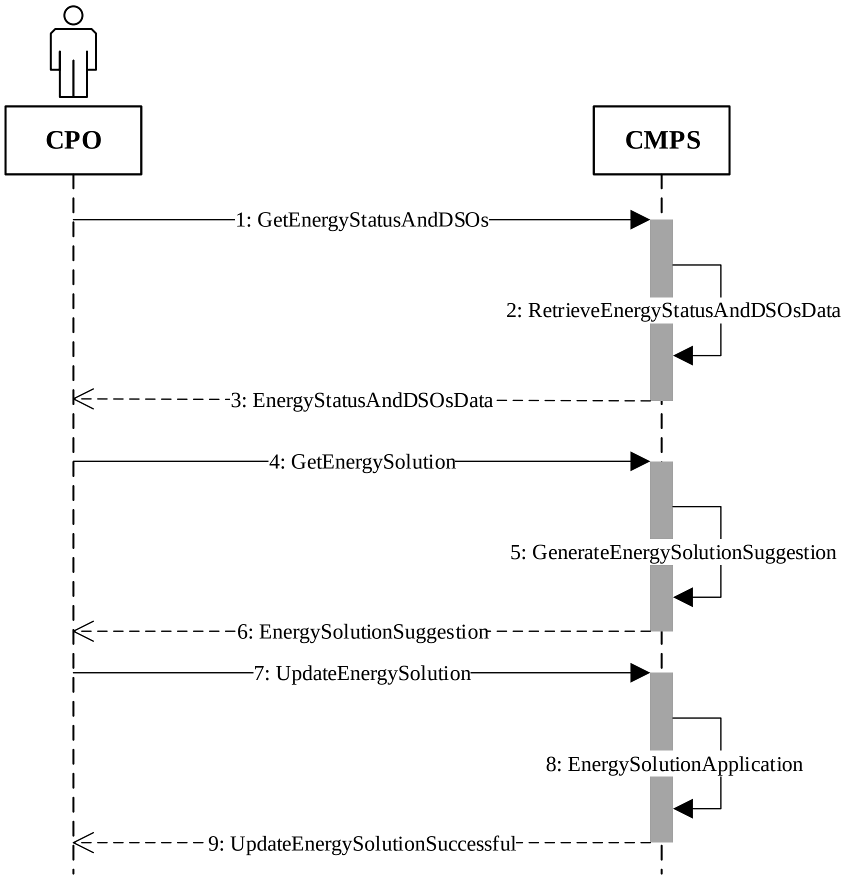


Figure 3-2-12 Sequence diagrams of "CPO chooses an energy solution for charging"

3.2.3 Requirements

Requirements	Description
R1	The system should allow an unregistered end user to register an account.
R2	The system should allow a registered end user to insert data about personal, vehicle, or cell phone and email binding information.
R3	The system should allow a registered end user to authorize eMSP to bind their own schedule, location information and vehicle battery status.
R4	The system should allow a registered end user to search charging slots.
R5	The system should be able to suggest a personalized charging slot.
R6	The system should allow a registered end user to book a charging slot in advance.

R7	The system should allow a registered end user to confirm the booking and initiate the charging process.
R8	The system should be able to control and monitor the charging of electric vehicles at the charge points.
R9	The system should be able to generate a bill for the charging service.
R10	The system should allow a registered end user to pay the bill.
R11	The system should allow a registered CPO to monitor charging stations.
R12	The system should allow a registered CPO to manage charging stations.
R13	The system should allow a registered CPO to acquire the current energy prices from DSOs.
R14	The system should be able to suggest a range of energy solutions.
R15	The system should allow a registered CPO to choose to select one of the suggested solutions, or manually input their own energy solution.
R16	The system must allow registered end users to login.
R17	The system must allow registered CPO to login.
R18	The system must be able to send notifications about the status and availability of the charge points, as well as any issues or updates related to the system.
R19	The system must be able to collect, store, and analyze data on the use of the charge points.
R20	The system must be able to ensure the security and integrity of the system.
R21	When a user registers, the system must authenticate that the user is associated to the specified electric vehicle

3.3.4 Mapping on Goals

Goals	**Domain assumptions**	**Requirements**
G1	D1, D2, D4, D6, D7	R1, R2, R3, R4, R16, R19, R20, R21
G2	D1, D2, D4, D6, D7	R1, R2, R3, R6, R7, R16, R19, R20

G3	D1, D2, D4, D6, D7, D10	R1, R2, R3, R8, R16, R19, R20
G4	D1, D2, D4, D6, D7, D10	R1, R2, R3, R8, R16, R18, R19, R20
G5	D1, D2, D4, D6, D7, D11, D12	R1, R2, R3, R7, R9, R10, R16, R18, R19, R20
G6	D1, D2, D4, D6, D7, D8	R1, R2, R3, R5, R16, R18, R19, R20
G7	D3, D5, D9	R11, R12, R17, R19, R20
G8	D3, D5, D6, D9	R11, R12, R17, R19, R20
G9	D3, D5, D6, D9, D10	R11, R12, R17, R19, R20
G10	D5, D13	R11, R13, R17, R19, R20
G11	D5, D13	R11, R14, R17, R19, R20
G12	D5, D13	R11, R15, R17, R19, R20

3.2.5 Mapping on requirements

Use cases	**Requirements**
End user registration and verification	R1, R20, R21
End user logins	R16, R20
End user manages account information	R2, R16, R20
End user searches or gets suggestion for charging slots	R3, R4, R5, R16, R19, R20
End user books a charge slot	R6, R16, R19, R20
End user charges vehicles and gets to know charging process	R7, R8, R16, R18, R19, R20
End user manages bills	R9, R10, R16, R19, R20
CPO monitors charging stations	R11, R17, R18, R19, R20
CPO manages charging stations	R12, R17, R18, R19, R20
CPO chooses an energy solution for charging	R13, R14, R15, R17, R18, R19, R20

3.3 Performance Requirements

The response time of eMall should be as fast as possible to ensure that charging requests are processed and executed efficiently. Ideally, the system should be able to respond to charging requests within seconds or milliseconds.

Secondly, for eMSPs and CPMS, a high throughput would be necessary to ensure that the system can handle a large number of requests from users trying to access charging points or manage their charging station. The system should also be able to accommodate a high number of concurrent users and charging stations, without experiencing performance degradation.

3.4 Design Constraints

3.4.1 Standards compliance

The charging service must comply with relevant electrical safety standards, such as the National Electrical Code (NEC) and the International Electrotechnical Commission (IEC) standards. The system must also comply with any applicable regulations or standards related to data privacy, cybersecurity, and network security.

3.4.2 Hardware limitations

The charging service needs to have a sufficient power output to charge the vehicles at a reasonable rate. This may be limited by the hardware and electrical capabilities of the charging station. The eMall needs to have reliable connectivity to the internet in order to communicate with the smart charging service. This may be limited by the hardware and infrastructure of the network.

3.5 Software System Attributes

Nonfunctional Requirements	**Attributes**	**Description**
NFR1	Reliability	The system must be available and functional at all times, with minimal downtime for maintenance or repairs.

NFR2	Availability	The system must be easy to use and navigate, with clear instructions and intuitive interface.
NFR3	Security	The system must protect sensitive user data and financial transactions from unauthorized access or tampering.
NFR4	Maintainability	The system must be able to handle updates and maintenance without significant downtime.
NFR5	Portability	The system must be compatible with a variety of devices, including smartphones, tablets, and desktop computers.

4. FORMAL ANALYSIS

This section should include a brief presentation of the main objectives driving the formal modeling activity, as well as a description of the model itself, what can be proved with it, and why what is proved is important given the problem at hand. To show the soundness and correctness of the model, this section can show some worlds obtained by running it, and/or the results of the checks performed on meaningful assertions.

4.1 Alloy Code

```
// sig Time represents a specific point in time, with a date, hour, and minute
sig Time {
  date: Int,
  hour: Int,
  minute: Int
}

// enum Boolean represents a boolean value (either true or false)
enum Boolean { true, false }

// sig EndUser represents an end user of the system, with fields for their ID, email, phone number, address, bill, schedule, car, password, and eMSP
sig EndUser{
  id: Int,
  email: String,
  phoneNumber: String,
  address: String,
  bill: one Bill,
  schedule: set Schedule,
  car: one Car,
```

```
  password: String,
  emsp: one eMSP
}

// sig Report represents a report, with fields for a head and context
sig Report{
  head: String,
  context: String
}

// sig SuggestionEnduser represents a suggestion for an end user, with fields for a charging station, car, and slot
sig SuggestionEnduser{
  chargestation: one ChargingStation,
  car: one Car,
  slot: one Slot
}

// sig SuggestionCPO represents a suggestion for a CPO, with fields for charging stations and cars
sig SuggestionCPO{
  chargestations: one ChargingStation,
  cars: set Car
}

// sig Bill represents a bill, with a field for the amount
sig Bill {
  amount: Int
}

// sig Schedule represents a schedule, with fields for a start time, things, and end time
sig Schedule {
  start: one Time,
  things: String,
  end: one Time,
}

// sig Location represents a location, with fields for latitude, longitude, and address
sig Location {
latitude: Int,
longitude: Int,
address: String
}

// sig Car represents a car, with fields for its ID, battery status, charging status, location, battery capacity, slot, threshold, and charging station
sig Car {
```

```
    id: Int,
    batteryStatus: Int,
    isCharging: Boolean,
    location: one Location,
    batteryCapacity: Int,
    slot: lone Slot,
    threshold: Int,
    chargestation: lone ChargingStation
  }

  // sig Battery represents a battery, with fields for capacity, energy, and price
  sig Battery {
    capacity: Int,
    energy: Int,
    price: Int
  }


  // sig ChargingStation represents a charging station, with fields for its location, cost, special offers, cars, slot types, cpms, slot number, available energy batteries, charged number, available slot number, dso, energy in battery, energy in DSO, battery, and threshold
  sig ChargingStation {
    location: one Location,
    cost: Int,
    specialOffers: set SpecialOffer,
    cars: set Car,
    slotTypes: set SlotType,
    cpms: one CPMS,
    slotnumber: Int,
    avialableenergybatteries: Int,
    chargednumber = Int,
    avialableslotnumber = Int,
    dso: one DSO,
    energyinbattery: Boolean,
    energyindso: Boolean,
    battery: one Battery,
    threshhold: Int
  }

  // sig SlotType represents a type of slot, with fields for the slots, type, slot number, availability, available number, charged number, estimated free time, and price
  sig SlotType {
  slots: set Slot,
  type: one Type,
  SlotNumber: Int,
  avialable: Boolean,
  avialablenumber: Int,
```

```
chargednumber: Int,
estimatedFreeTime: Time,
price: Int
}

// sig Slot represents a slot, with fields for the type, charge time, availability, power absorbed, estimated free time, and price
sig Slot {
id: Int,
type: one Type,
chargeTime: one Time,
ifavailable: Boolean,
powerAbsorbed: Int,
estimatedFreeTime: Time,
price: Int,
cost: Int
}

// enum Type represents the types of slots (slow, fast, or rapid)
enum Type { slow, fast, rapid }

// sig SpecialOffer represents a special offer, with fields for a start time, end time, and discount
sig SpecialOffer {
start: Time,
end: Time,
discount: Int
}

// sig CPO represents a CPO (Charging Point Operator), with fields for their ID, username, password, charging stations, DSOs, cpms, money, and cars
sig CPO {
id: Int,
username: String,
password: String,
chargingStations: set ChargingStation,
dsos: set DSO,
cpms: one CPMS,
money: Int,
cars: set Car
}

// sig DSO represents a DSO (Distribution System Operator), with fields for the price and provider
sig DSO {
price: Int,
provider: String
}

```

```
// sig CPMS represents a CPMS (Charging Point Management System), with fields for the charging stations, DSOs, money, threshold, and suggestionCPO
sig CPMS {
chargingStations: set ChargingStation,
DSOs: set DSO,
money: Int,
threshhold: Int,
suggestionCPO: set SuggestionCPO
}

// sig eMSP represents an eMSP (Energy Management Service Provider), with fields for the end users, charging stations, suggestionenduser, report, and threshold
sig eMSP {
endUsers: one EndUser,
chargestations: set ChargingStation,
suggestionenduser: set SuggestionEnduser,
report: Report,
threshhold: Int
}

// pred updateLocation updates the location of a car
pred updateLocation[newLocation: Location, c: Car] {
c.location = newLocation
}

// pred updateSchedule updates the schedule of an end user
pred updateSchedule[newSchedule: one Schedule, e: one EndUser] {
e.schedule = newSchedule
}

// pred StartChargeCar starts the charging process for a car at a charging station
pred StartChargeCar[r: Report, cs: one ChargingStation, t,t': Time, s: one cs.slotTypes.slots, e: EndUser, c: one e.car ] {
  c.isCharging = true
  cs.avialableslotnumber = cs.avialableslotnumber -1
  cs.chargednumber = cs.chargednumber + 1
  cs.cars = cs.cars + c
  cs.slotTypes.avialablenumber =  cs.slotTypes.avialablenumber - 1 implies cs.slotTypes.type = s.type
  cs.slotTypes.chargednumber =  cs.slotTypes.chargednumber +1 implies cs.slotTypes.type = s.type
  cs.slotTypes.avialable = false implies cs.slotTypes.type = s.type and cs.slotTypes.avialablenumber = 0
  c.slot = s implies s.ifavailable = true
  c.chargestation = cs
  c.slot.ifavailable = false
  c.slot.estimatedFreeTime = t'
  c.slot.chargeTime = t
```

```
  c.location = cs.location
  r.head = "Start charge"
  r.context = "Your car begins to charge"
  e.emsp.report = e.emsp.report + r
}

// pred findnearbychargestation to find the nearby chargestations
pred findnearbychargestation[e: eMSP, cs: some ChargingStation] {
  e.chargestations = cs
}

// pred bookingcharge to book a slot in a certain chargestation
pred bookingcharge[r: Report, sc: Schedule, cs: one ChargingStation, e: one EndUser, c: one e.car, s: one cs.slotTypes.slots, t',t'': Time] {
  sc.start = t'
  sc.end = t''
  sc.things = "Charging"
  e.schedule = e.schedule + sc
  cs.avialableslotnumber = cs.avialableslotnumber -1
  cs.chargednumber = cs.chargednumber + 1
  cs.cars = cs.cars + c
  c.slot = s implies s.ifavailable = true
  c.slot.ifavailable = false
  c.slot.estimatedFreeTime = t''
  c.slot.chargeTime = t'
  cs.slotTypes.avialablenumber =  cs.slotTypes.avialablenumber - 1 implies cs.slotTypes.type = s.type
  cs.slotTypes.chargednumber =  cs.slotTypes.chargednumber +1 implies cs.slotTypes.type = s.type
  cs.slotTypes.avialable = false implies cs.slotTypes.type = s.type and cs.slotTypes.avialablenumber = 0
  r.head = "booking"
  r.context = "Your booking is successful"
  e.emsp.report = e.emsp.report + r
}

// pred EndChargeCar to end the charge process and report to EndUser
pred EndChargeCar[r: Report, cs: one ChargingStation, t,t': Time, e: EndUser, c: one e.car] {
  c.isCharging = false
  cs.avialableslotnumber = cs.avialableslotnumber + 1
  cs.chargednumber = cs.chargednumber - 1
  cs.slotTypes.avialablenumber =  cs.slotTypes.avialablenumber +1 implies cs.slotTypes = c.type
  cs.slotTypes.chargednumber =  cs.slotTypes.chargednumber - 1 implies cs.slotTypes = c.type
  cs.slotTypes.avialable = true
  cs.cars = cs.cars - c
  e.car.slot.ifavailable = true
```

```
  e.bill.amount = e.bill.amount + c.slot.cost - cs.specialOffers.discount
  c.slot.cost = 0
  c.slot = none
  c.chargestation = none
  r.head = "End charge"
  r.context = "Your car ends the charge, and you can select to pay"
  e.emsp.report = e.emsp.report + r
}

// pred PayForService to allow EndUser pay for his service
pred PayForService[e: one EndUser, C: one CPMS] {
  C.money = C.money + e.bill.amount
  e.bill.amount = 0
}

//pred ChargingAdvice for EndUser is to advise user to charge for his car when his car's energy is not enough
pred ChargingAdvice[e: one EndUser, cs: one ChargingStation, r: Report, c: one e.car] {
  r.head = "ChargingAdvice"
  r.context = "Your car needs to be charged"
  e.emsp.report = e.emsp.report + r implies c.batteryStatus < e.emsp.threshhold
}

// pred monitorExternal to allow CPO monitor the External state of charge stations
pred monitorExternal[c: CPO, cs: one c.cpms.chargingStations] {
  c.chargingStations = c.chargingStations + cs
}

// pred monitorInternal to allow CPO monitor the Internal state of charge stations
pred monitorInternal[c: CPO, cs: one c.cpms.chargingStations] {
  c.cars = c.cars + cs.cars
}

// pred suggestionToCpo to allow CMSP suggest to CPO
pred suggestionToCpo[sc: one SuggestionCPO, c: CPO, cs : one c.cpms.chargingStations] {
sc.chargestations = cs
sc.cars = cs.cars
c.cpms.suggestionCPO = c.cpms.suggestionCPO + sc
}

// pred selectDSO to allow CPO select suitable DSO
pred selectDSO[c: CPO, D: DSO] {
  c.dsos = c.dsos + DSO
}
```

```

// pred DistributDSO to allow the CPO distributes a dso to chage station
pred DistributDSO[c: CPO, cs: one c.cpms.chargingStations, d: one c.dsos] {
  cs.dso = d
}

// pred suggestionToEnduser to allow the CPMS suggest eMPS
pred suggestionToEnduser[se: one SuggestionEnduser, e: EndUser, c: one e.cars] {
  se.car = c
  se.slot = c.slot
  se.chargestation = c.chargestation
  e.emsp.suggestionenduser = e.emsp.suggestionenduser + se
}

// pred SelectEnergy allow ChargingStation select energy according to the battery and DSO
pred SelectEnergy[cs: ChargingStation] {
  cs.energyindso = true implies cs.battery.energy < cs.threshhold
  cs.energyinbattery = false implies cs.battery.energy < cs.threshhold
  cs.energyinbattery = true implies cs.battery.energy > cs.threshhold
  cs.energyindso = false implies cs.battery.energy > cs.threshhold
}

// pred DeterminePrice allow charge stations determine the price according to selected energy
pred DeterminePrice[cs: ChargingStation] {
  cs.slotTypes.slots.price = cs.dso.price implies cs.energyindso = true
  cs.slotTypes.slots.price = cs.battery.price implies cs.energyinbattery = true
}

// the fact
fact eMobility{
  all e1, e2: EndUser | e1.email != e2.email
  all e: EndUser | #e.schedule > 0 and #e.car >= 1
  all c: Car | c.batteryStatus >= 0 and c.batteryStatus <= 100 and (c.chargestation in ChargingStation) <=> c.isCharging=true and c.batteryCapacity >= c.batteryStatus and (c.slot in Slot) <=> c.isCharging = true
  all cs: ChargingStation | #cs.slotTypes > 0 and cs.threshhold > 0 and cs.slotnumber > 0
  all st: SlotType | #st.slots > 0 and st.SlotNumber > 0 and st.price > 0
  all SO: SpecialOffer | SO.discount > 0
```

```
  all cpms: CPMS | #cpms.chargingStations > 0 and cpms.threshhold
 > 0 and cpms.money >= 0
  all t: Time | t.date >= 0 and t.hour >=0 and t.minute >= 0
  all C: CPO | #C.dsos > 0
}

// Dynamic Model
pred world {
  #EndUser >=30
  #CPO >=6
  #DSO >=3
}

run world for 5
```

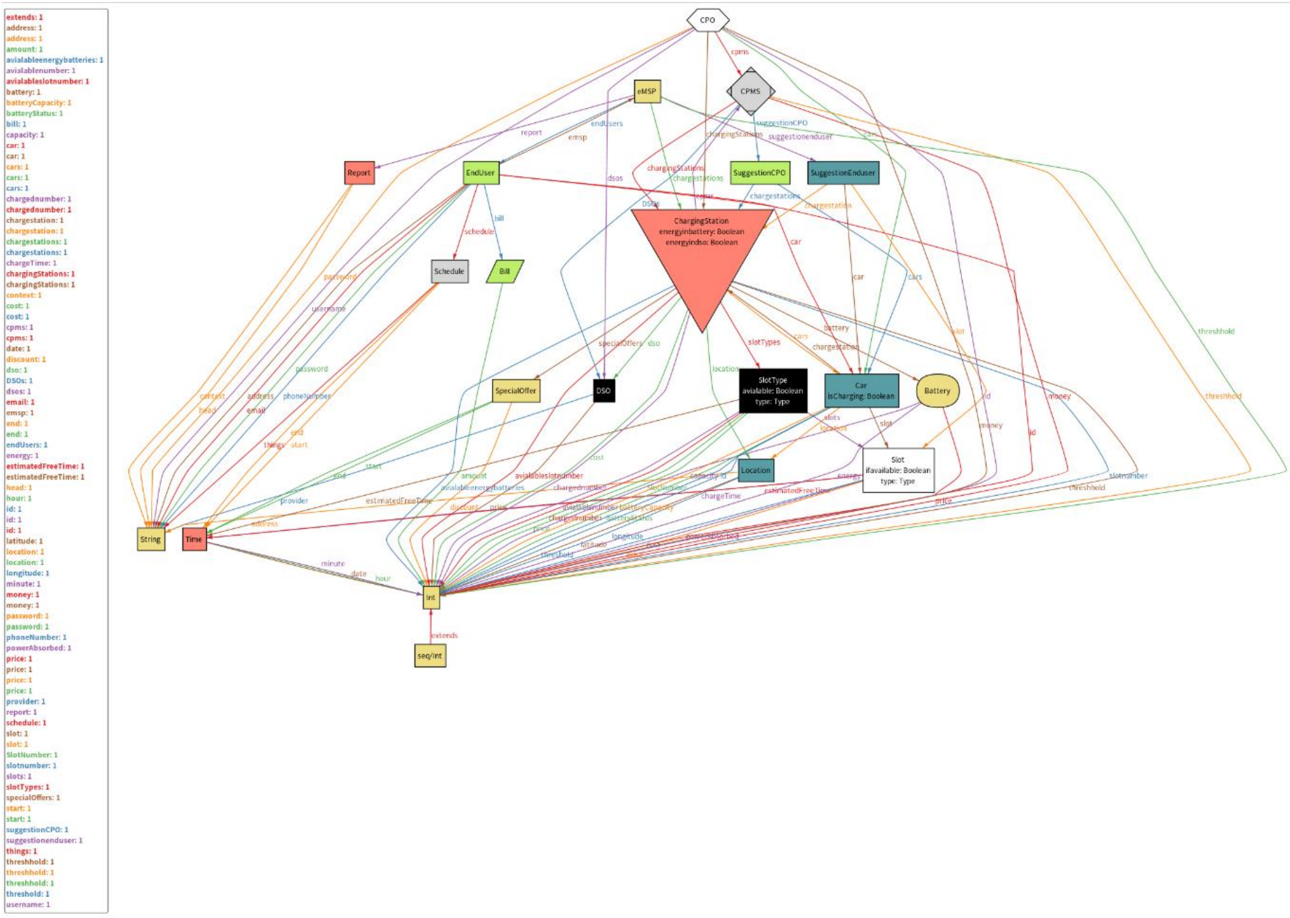
4.2 The model description

In the model we focus on the relations between CPO, End User, eMPS, Charging Station, CPMS and DSO. With this, we want to show, among other things, the following:

1. Every End User has an eMPS and a set of cars. Every car has a location
2. Every CPO has a CPMS which contains my charging stations and a set of DSOs.
3. Every charging station has a set of slot type which has a set of slots and a DSO.
4. Every DSO is held by a set of CPO.

4.3 Dynamic model

We also modeled some dynamics of the system. However no additional constraints are shown with that.



4-3-1 Dynamic model

5. EFFORT SPENT

5.1 Haotian Zhang's effort

Task	**Time spent**
Introduction	8 h
Overall description	20 h
Specific requirements	20 h
Formal analysis	2 h
Reasoning	5 h
Total	**55 h**

5.2 Jiaheng Xiong’s effort

Task	**Time spent**
Introduction	2 h
Overall description	2 h
Specific requirements	3 h
Formal analysis	50 h
Reasoning	1 h
Total	**57 h**

5.3 Chenyu Zhao’s effort

Task	**Time spent**
Introduction	6 h
Overall description	20 h
Specific requirements	20 h
Formal analysis	3 h
Reasoning	3 h
Total	**52 h**

6. REFERENCES

[1] Davis, Steven J., and Ken Caldeira. "Consumption-based accounting of CO2 emissions." *Proceedings of the national academy of sciences* 107.12 (2010): 5687-5692.

[2] Lindsey, Rebecca. “*Climate Change: Atmospheric Carbon Dioxide*.” NOAA Climate.gov, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.