POLITECNICO
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e-Mobility for All

Requirements Analysis and Specification Document
(RASD)

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1 Introduction

1.1 Purpose

The main challenge of a massive deployment of electric mobility is the reduction of transportation's impact on climate by limiting the carbon footprint caused by our urban and sub-urban mobility everyday needs.

With this in mind, our aim is to develop and implement a new system called eMall having the purpose to expand the electric charging infrastructure with the means of realizing a world-wide network which fully connects all the actors involved in the charging processes. This is achieved by making all the back-end operations and transactions transparent to the everyday user which is fully supported in the charging process.

eMall will act as a platform deployed as a mobile application and implemented through several servers (eMSPs) located throughout the globe allowing to monitor electric mobility by communicating with various CPOs, each of them administrated through a CPMS.

Thereby the platform with expose several services such as:

- knowing where to charge the e-vehicle (locate charging stations owned and managed by CPOs)
- planning charging processes in a way to limit constraints on our daily schedule giving the possibility to the system to access our personal calendar
- choose from various charging possibilities based on special offers set by CPOs which can dynamically decide from where to acquire energy to be distributed (from which DSO)

In order to guide the development step by step, the document will focus on the goals and requirements of the system to achieve.

1.1.1 Goals

The following table presents the goals of the system to achieve along with a brief description.

Goal	Description
G1	The eMSP should allow the user to obtain information about the charging stations.
G2	The eMSP should allow the user to book a charge in a certain charging station before the vehicle runs out of energy.
G3	The eMSP should allow the user to manage the charging process (from its start to the payment) once he/she reaches the charging station.
G4	The eMSP should give the possibility to the user to receive updates on the charging process.
G5	The eMSP should show the user the optimized path to the destination based on the residual energy of the vehicle.
G6	The CPMS should allow the CPO to handle the acquisition of energy from external third party providers (DSO).
G7	The CPMS should allow the CPO to gather information about the DSOs' current price of energy.
G8	The CPMS should manage information about the location, external and internal status of a charging stations.
G9	The CPMS should provide energy according to the type of socket chosen by the user.
G10	The CPMS should allow the CPO to decide where to get energy from (station batteries, DSO, mix).

1.2 Scope

This document focuses on the interaction between the most important stakeholders, even though several ones might be left undefined.

In particular we consider the users, which might want to use the services provided by the system, the CPOs (e.g. ENEL X, IONIX or others) physically deployed through charging stations and administrated by ad hoc pre-implemented CPMS sub-systems, and DSOs, external third party energy providers.

The system we are focusing on is the e-MSP, a remote sub-system (passive server) which receives requests from the several users and uses uniform APIs to interact with other external sources such as CPMSs and other systems.

1.2.1 World Phenomena

ID	Description
WP1	User's e-vehicle is running out of energy.
WP2	User physically looks for an available charging station.
WP3	Charging station's socket doesn't work properly.
WP4	Catastrophic environmental disasters (earthquakes, avalanches, hurricanes, floods, heavy storms).
WP5	Accidental damages occurred on the infrastructures.
WP6	User prepares the vehicle (parks, connects the charging socket) for the charging process.
WP7	There is a fully geographical network coverage and connectivity to the system is ensured.

1.2.2 Shared Phenomena

ID	Description	Controller	Observer
SP1	The user looks up for a nearby charging station.	User	System
SP2	The user chooses the best charging station from the available ones based on its preferences.	User	System
SP3	The system shows the user information about the charging process.	System	User
SP4	The system shows the user several payment methods.	System	User
SP5	The system automatically decides from which DSO energy should be acquired.	System	User

1.3 Acronyms and Abbreviations

Below there's list of abbreviations used throughout the document.

Term	Definition
API	Application Programming Interface
COTS	Component Off The Shelf
CPMS	Charge Point Management System
CPO	Charging Point Operator
DMV	Department of Motor Vehicles (US equivalent of italian "Motorizzazione Civile")
DSO	Distribution System Operator
Dx	Domain Assumption number x
e-Mall	Electric Mobility for All (Software Name)
e-MSP	e-Mobility Service Provider
EV	Electric Vehicle
Gx	Goal number x
MTTR	Mean Time To Repair
MPI	Message Passing Interface
Rx	Requirement number x
RAFT	Algorithm regarding replication and consistency for distributed systems.
RASD	Requirements Analysis and Specification Document
SPx	Shared Phenomena number x
TCP/IP	Transmission Control Protocol (over Internet Protocol)
VIN	Vehicle Identification Number
WP	World Phenomena

1.4 Reference Documents

For the construction of this document, the specification document "Assignment RDD AY 2022-2023_v3.pdf".

1.5 Document Structure

1.6 Overview

2 Overall Description

2.1 Product Perspective

2.1.1 Scenarios

Unregistered user wants to use e-Mall The user Alice has just bought an electric car and wants to use e-Mall. She can only do so if she is registered, so through the index page of the corresponding site she fills the registration module by entering her personal information and vehicle details. e-Mall is integrated with the DMV's database to confirm the association between vehicle and owner, and with vehicle manufacturers' database to associate the vehicle owner with the vehicle details. After registering, Alice can finally use all the services offered by e-Mall: searching for charging stations, booking charging stations, scheduling trips and managing the charging process. Every time she uses the app data will be updated so that she is in control of any information, directly from the app. Now Alice can get in her car and make her first recharge thanks to e-Mall.

User looking up for charging stations and filters managing The user Cassandra is at home which is 10km away from the main town. She wants to charge her electric vehicle so she accesses e-Mall app from her smartphone by using her fingerprint. From the Home Page she selects the Searching Page to which she's being redirected. She can now choose to either let the system find the most convenient charging station based on the information about the vehicle's status (park location, battery level) acquired by e-Mall or to insert preferences (range of distance from current or remote position, range of price, preferred CPOs, preferred payment methods, availability of sockets, type of sockets, special offers) about the searching operation on her own. Cassandra wants to go get some groceries from the town centre so she inserts the destination of the grocery shop and wants to retrieve the most economic (range of price) nearby charging stations within 200m from it (distance range filter). The system provides a list of three charging stations and Cassandra decides to consult them from the map point of view. Two of them are available but characterized by a slightly high cost, meanwhile the last one is occupied but the system estimates that the charging process is about to end within the next 15 minutes, exactly the time Cassandra needs to reach the location. Furthermore, this last charging station is managed by a CPO providing a special offer lasting for other few hours. Cassandra reasons about the next step.

User booking a charge The user Mario notices that the car battery is not fully charged, so he decides to charge it. After searching for the charging stations nearest to him based on the search criteria (filters) entered, he chooses one, thus obtaining more information regarding the charging station (available sockets, price, special offer,...). If the information convinces Mario, he makes the reservation by inserting the initial and end time of the charging process. He clicks on the BOOK button, and if he receives a notification of successful booking, this means that he can reach the charging station and the book is added to the user's calendar, otherwise, Mario will receive a notification with the error that occurred (eg. at that time on his calendar he has an appointment so you have an overlap), in which case Mario will have to choose a different timestamps.

User scheduling a travel The user Vittorino has to travel from Milan to Budapest for a business trip the next Monday. He is registered to the e-Mall app which has updated information about Europe's most recent electric mobility infrastructures. From Home Page he clicks on the Travel Button which immediately redirects him to the Travel Page. Vittorino inserts the destination he wants to reach, the day and time by which he needs to arrive and suggests the app to assume the vehicle will be fully charged by the time he leaves. The app calculates two convenient routes (using algorithms like Dijkstra or Bellman-Ford) Vittorino could choose from based on the time he wants do start the trip but also detects an overlap between the trip time and a certain event inserted onto the user's calendar. A notification is showed to Vittorino which clearly forgot to reschedule the event on the calendar and decides to continue to choose from the routes proposed anyway, ignoring the notification. Later on he will reschedule his event.

User's vehicle is running out of battery Mrs. Braz is on her way to Portugal to visit her family. After a few hours of driving, Mrs. Braz is focused on the road and does not notice that her car's battery is getting low, so having arrived at the remaining 10% the system recognizes that the battery is getting low and approaching zero, so it searches for the most convenient charging stations close to the car's current location, and sends a notification to Mrs. Braz advising her to recharge the vehicle at the recommended charging station as soon as possible.

Charging process executing (failure managements) The user Nicola has booked a charge at a charging station through e-Mall. He reaches the charging stations, parks his car, and connects the socket. Once he connects the socket he receives a notification with the details of his reservation and with the option to start the process. He chooses to start the process and in real time, both from the app and on the display of the charging point, he receives details about the status of the charging that is taking place according to the strategy defined by the CPMS (take advantage of the battery inside the charging point, or use an external DSO). As soon as it reaches 100%, charging is complete and Nicola can disconnect the socket and leave the area, after having payed for the service. However, if some unforeseen event happens during the charging process (the socket is accidentally disconnected, the vehicle's motor is turned on, or the charging point has problems), the charging is suspended and details of the problem appear on his own device with options to fix or report what happened to the CPO, or even stop the process and pay only for how much energy was dispensed. Nicola is very pleased with such a smart process and is looking forward to charging his vehicle again by using e-Mall application.

Payment The user Stefan is taking a walk while he is waiting for his vehicle to be fully charged at the charging station. Suddenly his phone rings and he notices a notification from e-Mall app has been received. Stefan accesses the app by using his fingerprint. He then realizes his vehicle is up about to reach the desired battery level decided at the booking phase and decides to reach the charging station. Finally continues using the app and selects one from the payment methods provided, all supported by 3DS secure methods. He waits for the transaction to be completed but a failure occurs and the app suggests to choose another payment method. He then realized his card just expired two days ago and decides to use PayPal in order to complete the payment. Once the transaction has finally completed the app suggests Stefan to disconnect the socket and leave as soon as possible as another charging process is about to get started within the next 10 minutes at that location.

CPO makes special offer initiative At the end of each month Enel X analyzes the metadata acquired on the distribution of energy through the charging stations and decides which one was the most profitable within a certain area. This November, statistics state that the charging station located at the Monte Baldo Autogrill on A4 motorway brought the highest profit within the last three months in the area. Thereby, Enel X decides to make a special offer on that charging station and on the nearby one in order to populate them even more with EVs. The system, by using machine learning algorithms, suggests that a percentage between 20% and 30% of sale for three consecutive days would increase the number of EVs by 10% and would also lead to the rise of customer fidelization. Enel X manually sets the special offer by putting a 25% sale for the next three days for both the charging stations. The system dynamically calculates the most convenient way to acquire the energy and changes the DSO on the fly deciding to store it on the batteries located at the charging station.

2.1.2 Class Diagram

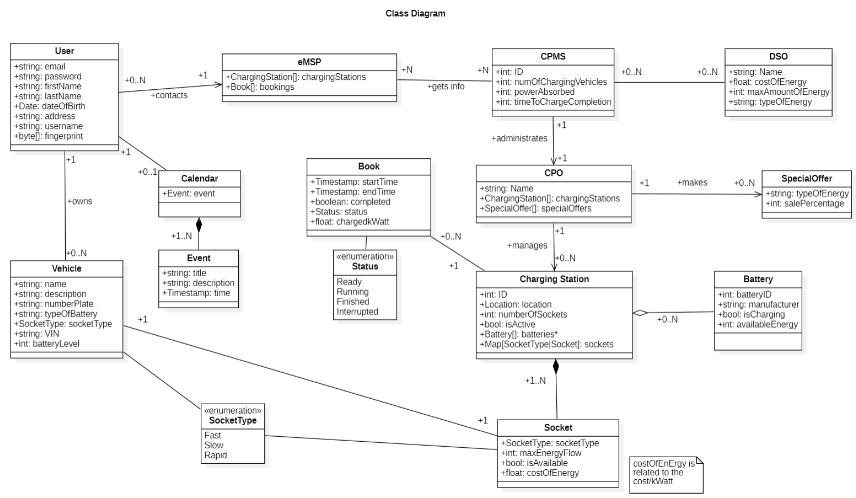

Figure 1: The picture above shows the Class Diagram of the main components of the eMall system

2.1.3 State Diagrams

This section is focused on the statecharts of some aspects of eMall system.

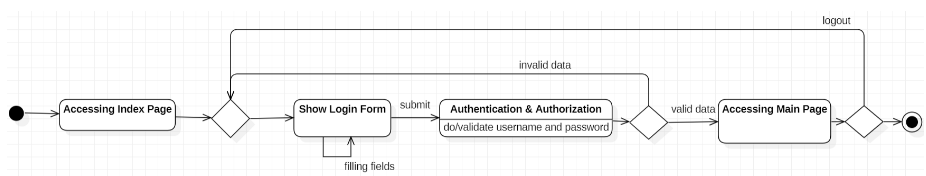

Figure 2: Login, Authentication and Authorization State Diagram

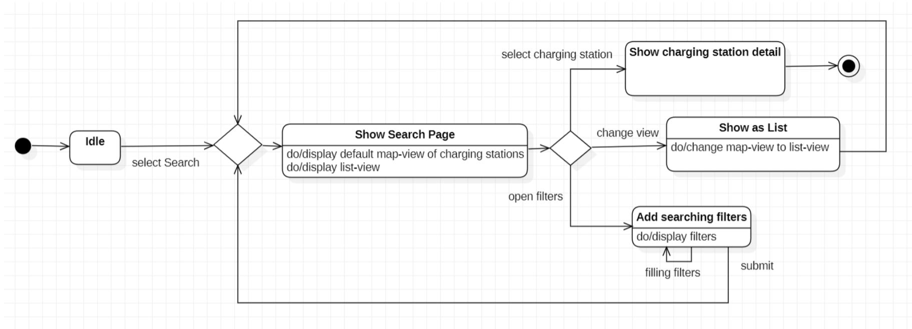

Figure 3: Looking for Charging Station State Diagram

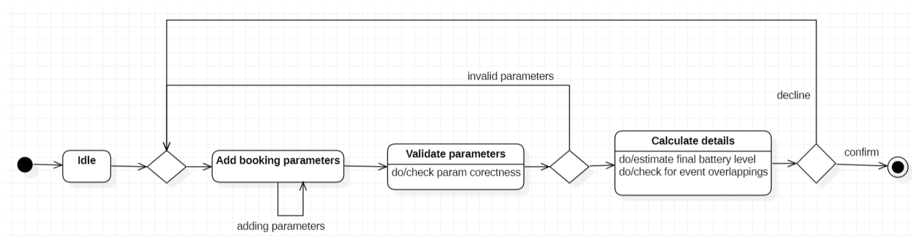

Figure 4: Booking a Charing Station State Diagram

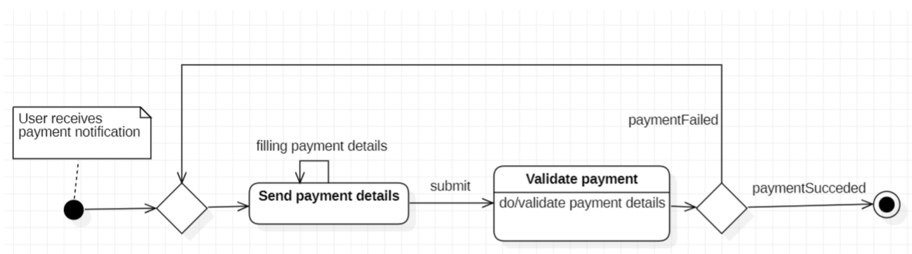

Figure 5: Payment State Diagram

2.2 Product Functions

In the next section we present the main functionalities introduced by e-Mall.

2.2.1 Identification of the nearby charging points

One of the most important aspects of the system is the identification of charging stations.

The search for charging stations can be carried out in different ways, quickly, by using the GPS, which returns a list of the nearest charging stations to the vehicle, by applying filters to the search, such as the maximum distance the charging station must be from the vehicle, or by choosing a charging station anywhere on the map.

Once the user has received a list of the nearest charging stations, he can see details of each charging station such as the price of charging, the types of sockets that are available, and some other detailed information about the charging station.

If the information on the charging station convinces the user then he can carry out the next booking operation, otherwise he can return to the list of charging stations to look in detail at other charging stations and choose the one he prefers.

2.2.2 Efficient and optimized charging station's booking system

The booking process is another key aspect of the system; after looking at the charging stations, there is the booking phase.

The system allows the user to choose a start time and an end time for recharging, also estimating the battery level that will be reached at the end of recharging based on the types of sockets of the station, so that the user can choose to book for a longer recharging time if he/she needs it.

Once the time has been chosen, the system checks the user's calendar, to which it has access thanks to the smart function implemented on the system, looking for overlapping events. In the event of overlapping the system notifies the user of the presence of simultaneous events and allows the user to choose another time slot.

If there is no overlapping, the user can continue by finishing the booking process, and can reach the booked charging station to start recharging.

2.2.3 Interoperability and connectivity ensured for all the Infotainment systems (cars manufacturers)

The eMall system is fully connected with the infotainment systems of various EVs, due to the integration with various car manufacturers and full support for Android Auto or Apple Car. Connection to the system is ensured through the mobile network connection, to be assumed reliable, of the smartphone associated to the car and the GPS antenna.

2.2.4 Fault tolerance towards operations

Since some operations may occur under precarious network and geolocation conditions, the system implements a mechanism to handle client-side faults: from re-transmitting data, to waiting for a more stable connection. On the server side, infrastructure redundancy and geographic distribution of machines allows for greater up-time and response to requests from outside, as well as disaster recovery.

2.2.5 Sharing knowledge through the network among participants

The system will provide the possibility to share your charging experience at a certain charging station by providing a rating along with a comment once the charging process has finished or interrupted by the user. This will enhance or decrease the charging station visibility on the map based on the level of agreement between the users who took advantage of its services.

The overall rating will be periodically notified to the specific CPO which will analyse the data and decide how to further proceed. The rating is totally subjective and could be influenced by the environment, the access to the station or the nearby infrastructure such as restaurants, shops or other activities. All this data will be used to enforce the the system and upgrade it based on the users requests.

2.2.6 Collect and share information for Data Analytics purposes

The system collects data about users as long as it can track their movements and their decisions. The eMall back end will have a hidden-to-the-user component which will be given the function to analyze data coming from different users, to profile them and to compute meta-data and statistics about system's efficiency and find ways to improve the effect on the everyday user's routine.

2.3 User Characteristics

The user is the main character of e-Mall platform. There are two types of users; an "unregistered" user, that is a user that needs to register to the system in order to use the functionalities provided, and the "registered", who is able to log in to the system and improve its electric mobility routine by using the functionalities provided by the system such as looking for a charging station from anywhere and at any time.

Finally we have the CPOs, an actor who can access the system through its own CPMS and implicitly authenticated and so authorized. Each CPO manages its charging stations, by monitoring them, activating/deactivating them, checking their status, decides to make special offer initiatives and dynamically chooses from which DSOs to acquire energy from.

2.4 Assumptions, Dependencies and Constraints

2.4.1 Domain Assumptions

ID	Description
D1	There exist uniform APIs allowing the user to interact through the eMSP with one or multiple CPOs.
D2	There exist uniform APIs allowing the CPOs to interact with one or multiple DSOs through the CPMS.
D3	The user inserts valid data when performing the registering phase.
D4	The user approaches the charging station once he/she has book a charge within a certain time.
D5	The user interacts with the charging station by following the instructions attached to the charging station.
D6	The user interacts with eMSP by following the guideline provided by the eMSP.
D7	Absence of inconsistencies between the a-priori defined energy flow offered by the DSO and the actual one used to charge the vehicle.
D8	The user pays the booked service after the charging process has finished.
D9	The user schedules a travel to a timestamp greater than the current one.
D10	The system works properly in absence of inconvenient and unexpected events.
D11	The user frees the charging station once the charging process has finished.

3 Specific Requirements

3.1 External Interface Requirements

3.1.1 User Interfaces

The eMall user interface is an application used by:

- a non-registered user, who can register by providing the information requested during the registration process
- a registered user, allowing him to log in by entering the credentials used during registration, or by using the fingerprint
- a logged-in user, allowing him to use the various functionalities provided by the system, such as searching and booking a charging station

The system must be designed to run both on the smart-phone and on the vehicle's infotainment system. It should therefore be simple and user-friendly, so that it can also be used while driving and by any type of person.

3.1.2 Hardware Interface

From a hardware point of view, the system must be able to receive input data, to perform login, registration and display information on the screen such as the nearest charging station and battery charging status.

The system is interconnected with the various charging stations and so therefore knows their location by the means of GPS technology. This requires Internet connection in order to locate the vehicle worldwide and suggest the nearest charging station to reach.

The system must be connected to the EV's battery as it must display the battery charge status, during charging, and in the event of a low battery, to send a notification to the user in order to remind him/her to reach a charging station as soon as possible. The system-battery connection could be performed by using a black-box hardware device directly connected to the battery which main function is to acquire real-time data and send it to the system.

3.1.3 Software Interface

Linux was chosen as the system's operating system, which is very versatile and user friendly, to run on both smart-phones and the vehicle's infotainment. MPI (Message Passing Interface) was chosen to talk between the actual components inside the system, since in high performance networks we need higher level primitives for asynchronous and transient communication. On the other hand, communication with the CPMS and third parties (eg. for payment) uses the TCP/IP protocol.

3.1.4 Communication Interface

Most of the functionalities provided by the system return information, and only the registration, login and filter search operations allow the user to enter data.

There are 4 different interfaces that eMall utilizes:

- retrieval of nearest charging stations (either based on proximity, or based on filters provided)
- receipt of notification of successful or error booking
- receipt of notification when the charging process is complete
- at the payment stage (where you will be directed to a payment provider)

3.2 Functional Requirements

3.2.1 Use Case Diagrams

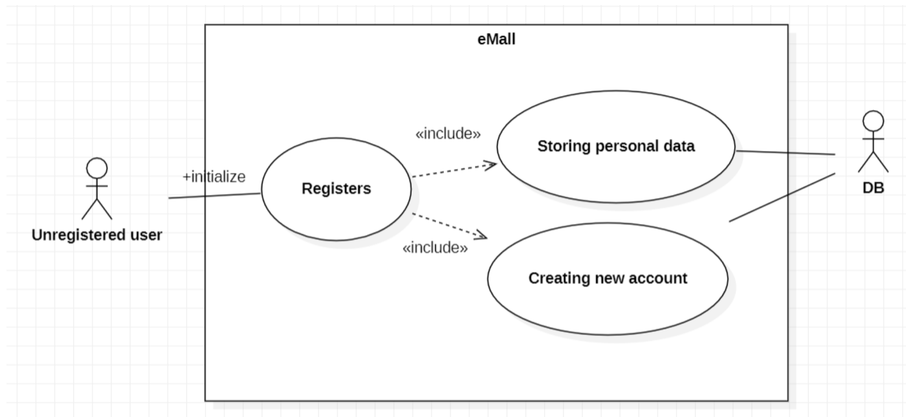

Figure 6: The picture above shows the use case of an unregistered user who wants to join eMall

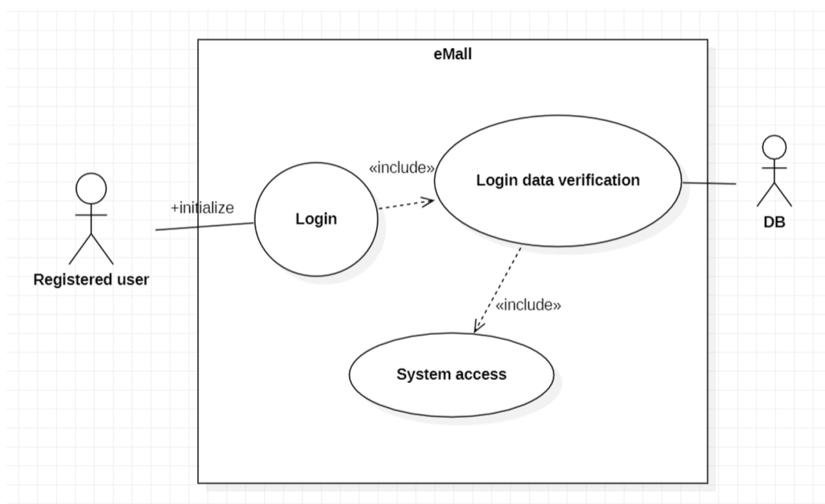

Figure 7: The picture above shows the use case of an registered user use eMall functionalities

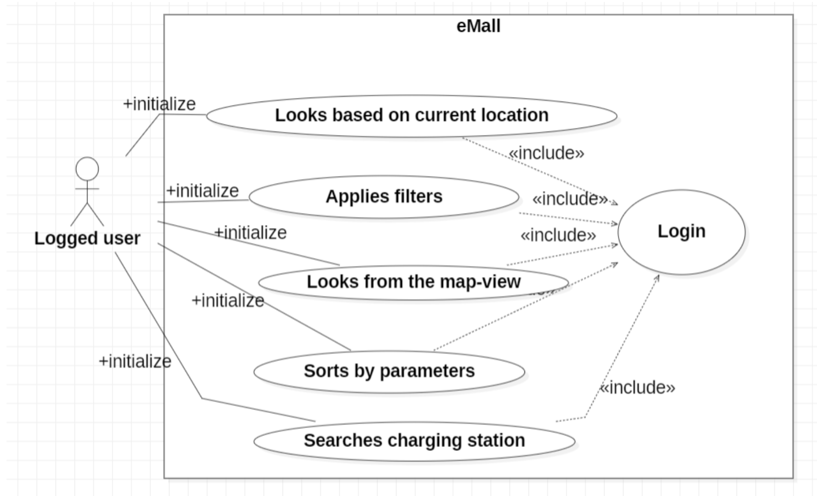

Figure 8: The picture above shows the use case of an logged user who wants to look for a charging station

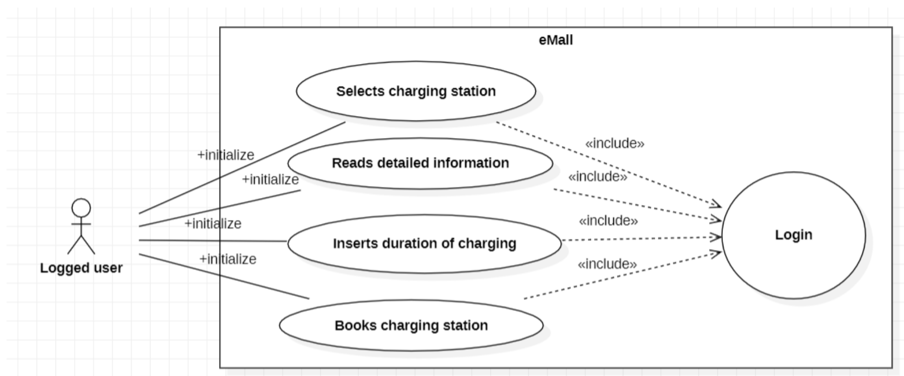

Figure 9: The picture above shows the use case of an logged user who wants to book a charging station

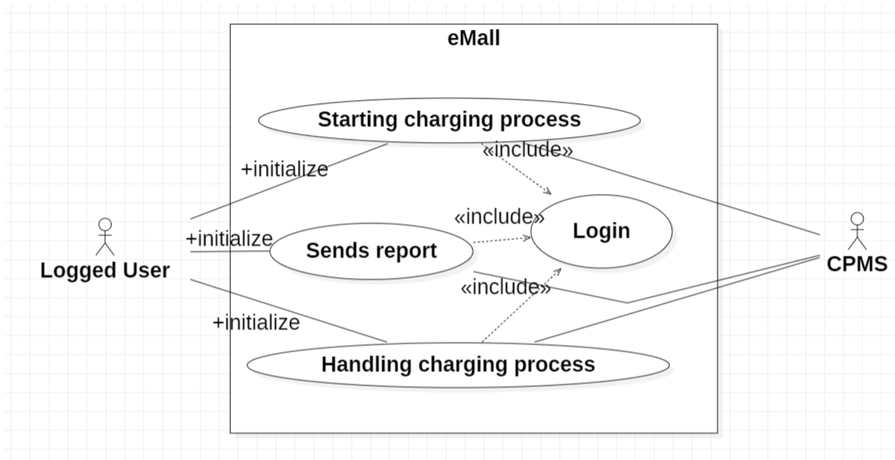

Figure 10: The picture above shows the use case of an ongoing charging process

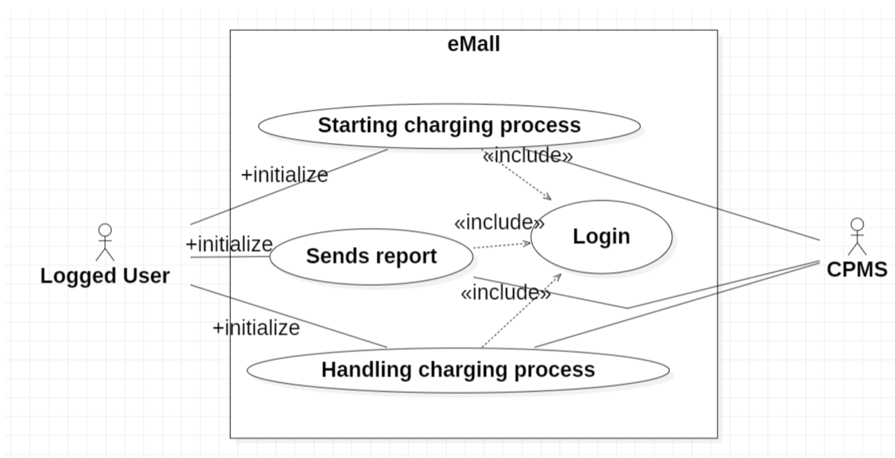

Figure 11: The picture above shows the use case of an ongoing charging process

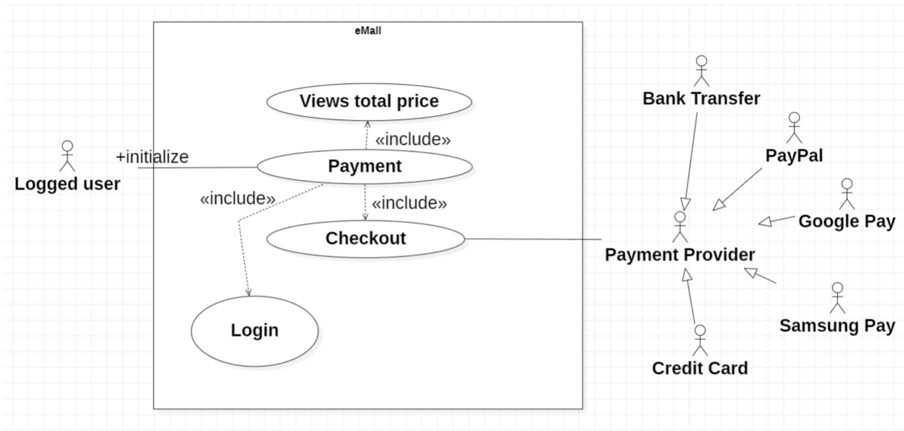

Figure 12: The picture above shows the use case of a Payment

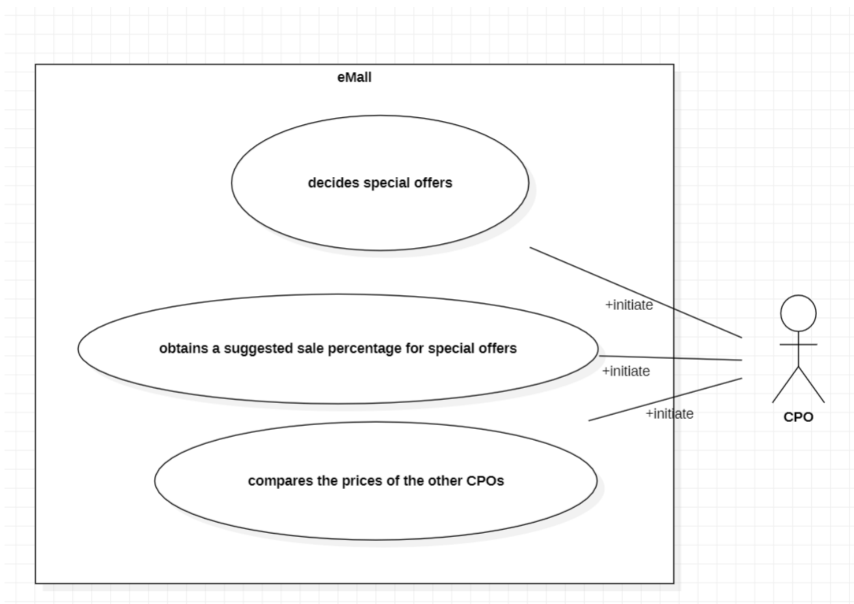

Figure 13: The picture above shows the use case of a CPO

3.2.2 Use Cases

Table 1: User registration

Actor	Unregistered user
Entry Condition	• The user does not have an account and is on the index page of the application.
Event Flow	1. The user clicks on "Create Account" 2. The user inserts his/her personal data: first and last name, date of birth, address, email address, username and password. 3. The user can also enter bio-metric data such as fingerprint. 4. The user enters an identification document to confirm his/her identity (ID card or driver's license) or uses a digital identity provider such as SPID or CIE. 5. The user enters the VIN of the vehicle(s) he wants to associate with his profile. By querying the DMV (Department of Motor Vehicle) dataset the system will confirm whether that vehicle is owned by the user or not. 6. If confirmation occurs, the vehicle manufacturer's dataset is also queried to associate the vehicle's details with the user, which will be updated in real time (or at least periodically). 7. e-Mall processes the information, verifies it, and returns a successful transaction message to the user and redirects it to the Home Page. 8. The user can remember the credentials for future access.
Exit Condition	• The account is created.
Exceptions:	• The user did not enter all the required data. • The user provided invalid data. • The query of the database of the civil DMV and/or the vehicle manufacturer was unsuccessful. In all cases the user receives a notification.

Table 2: User login

Actor	Registered User
Entry Condition	• User is registered, not logged in and on the e-Mall's index page.
Event Flow	1. User presses login button 2. User inserts either email address and password or uses fingerprint to access the application. 3. User submits 4. e-Mall processes the information and displays a success message after having checked
Exit Condition	• User is logged in to e-Mall.
Exceptions:	• User does not insert password or email before submitting. • User insert invalid email/password combination. • User does not have fingerprint saved. • User uses invalid fingerprint.

Table 3: Charging station look up

Actor	Logged user
Entry Condition	• The user is registered, logged in to the e-Mall app and on the Home Page.
Event Flow	1. The user presses the Search button which redirects the user to the Searching Page. 2. The user can either directly look up for the nearest charging stations using default preferences imposed by the system itself based on the information acquired by the calendar and the vehicle's Infotainment system by selecting Fast Search (e.g: battery status) or insert his own current preferences to filter the search. (further detailed info in the corresponding scenario). 3. The system looks up for the charging stations based on the searching preferences and returns a list of them. The list shows an overview station by station and can contain available charging stations which are waiting to be booked or even occupied charging station characterized by imminent ending charging process. Both of the types can be booked. Charging stations can also be visualized from a map view. 4. Based on the user's choice, he/she can select a certain charging station from the provided list in order to view further detailed information about it.
Exit Condition	• The user selects Exit/Home Page from the Searching Page. • Search operation succeeds and an the page is updated with requested data. Any of the above operations leads to the exit condition.
Exceptions:	• The user doesn't insert all mandatory data for the searching filters. • The user selects an invalid data for certain mandatory fields. If any of the above occurs, e-Mall shows the user a notification error message and recommends to retry.

Table 4: Charging station book

Actor	Logged user
Entry Condition	• A registered user, logged on to e-Mall, and about to look for a charging station.
Event Flow	1. The user selects a certain charging station from the list provided or chooses it from the map view. 2. Reads information about the charging station selected. 3. Selects the initial timestamp and the end timestamp to make a reservation for the charging station. 4. Presses button BOOK. 5. Receives ack for the booking (with the estimation of the battery level at the end of the charging process) or nack in case of failures (eg: overlapping of the timestamp with other events in the calendar) and the system requires other timestamps to be inserted.
Exit Condition	• An ack is received and a book is scheduled.
Exceptions:	• User unauthorized to book. • Overlapping with other events from the user's calendar. • Concurrent book operations between several different users on the same charging station within the same range of time.

Table 5: Charging process

Actor	Logged user
Entry Condition	• The user who already booked a reservation has arrived at the charging station, inserts the socket, and receives a notification on the e-Mall app in order to consent the start of the charging process.
Event Flow	1. The user receives the notification with a reminder to their reservation details. 2. The user starts charging by clicking on the "Start Charging" button on the app. 3. Energy is delivered according to the strategy dynamically defined by the CPMS (the energy source can be a DSO, or the internal battery if present, or both) which will impact on the duration of the recharge. 4. Charging stops when the end time of the booking is reached. 5. The user can monitor the charging status in real time either from the app, the vehicle's Infotainment system or the display located at the charging station (if present). 6. The user receives a notification that the recharge is completed.
Exit Condition	• Charging process has been completed
Exceptions:	• The socket is suddenly plugged out from the vehicle. • The user turns on the vehicle's motor. • User suddenly stops the charging process from the app before reaching the end time. In all cases, charging is suspended and the user is notified with options to fix the problem (if within his or her scope), send a report to the CPO, or stop charging definitely.

Table 6: Payment

Actor	Logged user
Entry Condition	• The user is registered, logged on to e-Mall, the charging process has finished and the system sent him/her a notification.
Event Flow	1. The user receives a notification about the completion of the charging process of the vehicle and is invited to: (a) reach the vehicle (b) pay for the service The above activities can be executed on the preferred sequence. (c) disconnect the socket from the vehicle and reconnect it to the charging station 2. The user confirms that the notification has been received and the system provides the user with different payment methods: (a) PayPal (b) Credit/debit card (c) Bank transfer (d) Several payment apps: e.g Google Pay, Samsung Pay, etc 3. The user provides payment based on the chosen payment method.
Exit Condition	• Payment transaction commitment is received by the system and notified to the user.
Exceptions:	• The user reached the card's daily limit. • Fake fraudulent purchase detection. • Card/PayPal account/Bank coordinates are invalid. • Payment transaction rolled back. If any of the above operations occurs the payment operation starts from scratch again.

Table 7: CPO makes price offer initiative

Actor	CPO
Entry Condition	• The CPO is already registered by default on the eMall and accesses on an ad hoc page made for statistics consultation.
Event Flow	1. The CPO consults its overall performance based on statistics and can sort the view on a certain charging station or on all of them. 2. The CPO selects one of its charging stations from a map view or a list view after having filtered and sort them based on profit degree, distance or other preferences. 3. The CPO is suggested to apply a possible special offer based on system automated calculations to maximize profit. 4. The CPO chooses to leave the decision to the system, to manually change the values of the special offer to apply or to reject the suggestion. 5. The CPO receives a notification that confirms the application of the special offer.
Exit Condition	• The CPO disconnects from the system.
Exceptions:	• The special offer fails to apply.

3.2.3 Requirements

ID	Description
R1	The eMSP should allow an unregistered user to register an account.
R2	The eMSP should allow a logged user to look for a charging station.
R3	The eMSP should be able to access the registered user's details (vehicle's Infotainment's system, user's calendar).
R4	The eMSP should be able to retrieve a list of the nearby charging stations based on the current position of the user's vehicle.
R5	The eMSP should be able to show the logged user the list of the nearby charging stations.
R6	The eMSP should allow the logged user to select a charging station from the list of nearby charging stations.
R7	The eMSP should be able to detect if the battery status is going below a fixed threshold.
R8	The eMSP should automatically show the logged user a list of nearby charging stations when the battery threshold is over-passed.
R9	The eMSP should allow the logged user to book a charge at the selected charging station.
R10	The eMSP should have access to the logged user's infotainment system.
R11	The eMSP should allow the logged user to insert filters on the looking up operation of the charging stations.
R12	The eMSP should allow the logged user to get information about the charging station selected (sockets available, type of sockets, costs, special prices).
R13	The CPMS should allow the CPO to choose the DSOs from which to acquire energy.
R14	The CPMS should allow the CPO to choose either to directly distribute the energy acquired or to store it into batteries collocated at charging stations.
R15	The CPMS should allow the user to monitor the information about the charging process (price, energy flux rate, estimated remaining time, battery's charging status).
R16	The CPMS should manage payment processes with different payment methods, responsible for the transactions.
R17	The eMSP should allow the logged user to decide the duration of the charging process.
R18	The CPMS should be able to dynamically calculate the residual time for the charging process.
R19	The eMSP should send notifies to user.

3.2.4 Mapping on Goals

Goal	Domains	Requirements	Why
G1	D1, D3, D6	R1, R2, R4, R5, R11, R12, R18	To obtain info about a charging station (nearby by default) and its status (dynamically calculated), there exists an API invoked by a logged user who inserts valid data (using filters) and follows instructions by the app.
G2	D1, D3, D4, D6, D9	R1, R2, R3, R4, R6, R9, R11, R12, R17, R18	Using API, a logged user books a charging station before his vehicle runs out of energy. He selects a charging station from a list (filters can be used), inserts valid data (charging duration), reaches the charging station and follows instructions to start the charging process.
G3	D1, D2, D5, D7, D8, D10, D11	R13, R14, R15, R16	Upon the charging station, user starts the charging process following the hints on the app. Absence of inconsistencies about energy transferred dynamically from DSO to charging station (also stored on local battery). User can monitor charging status and finally pays for service using a payment method.
G4	D1, D3, D5, D6, D7, D10	R1, R15, R16, R18, R19	The logged user can receive updates on the charging process through an API. Neither inconsistencies between the received energy and the one picked from the DSO nor inconvenience during the travels (between charging stations).
G5	D1, D3, D10	R1, R2, R4, R5, R6, R7, R8, R9, R10, R11, R12	System calculates trip path to destination inserted by logged user with reference to residual battery level of EV. No inconvenience occur during trip. Logged user books charging station on the path and system detect battery level threshold.
G6	D2, D7, D10	R13, R14	CPO uses API to access CPMS and handle acquisition of energy from DSOs based on its preferences and decides to distribute it immediately or store it into batteries.

G7	D2	R12, R13	CPO uses API to access CPMS and gather information about price of energy from DSOs to be shown on the app. CPO decides from which DSO to acquire energy from
G8	D1, D4	R12, R15	CPO uses API to access CPMS and handles information about internal and external charging station' status to be also shown to the user once it has been selected.
G9	D2, D7	R13	The system provides flow of energy based on the type of socket chosen by user. No inconsistencies between expected and provided energy dynamically decided from which to be acquired by the CPO
G10	D2, D7	R13, R14	The system either distributes energy directly acquired by DSOs or uses batteries as energy source based on automated methods or on CPOs' decisions made by the means of API. No energy inconsistencies are assumed.

3.2.5 Mapping on Requirements

Use Case	Requirements	Why
User registration	R1	
User login	R10, R19	
Charging station look up	R2, R3, R4, R5, R6, R7, R8, R11, R12	
Charging station book	R9, R10, R17	
Charging process	R13, R14, R15, R16, R18	
Payment	R16	

3.2.6 Sequence Diagrams

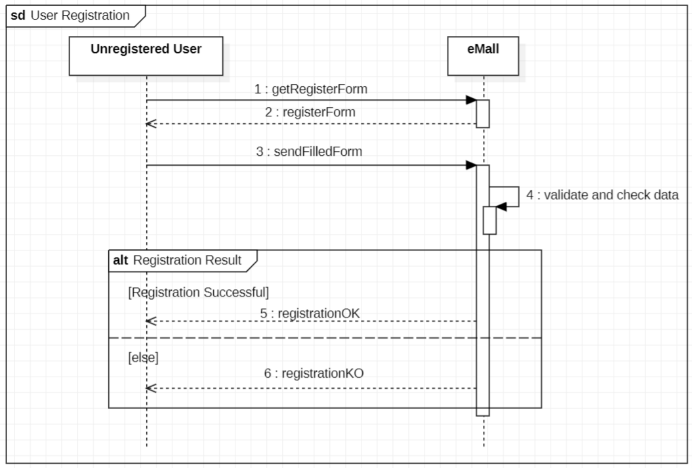

Figure 14: The above diagram shows the Sequence Diagram for User Registration

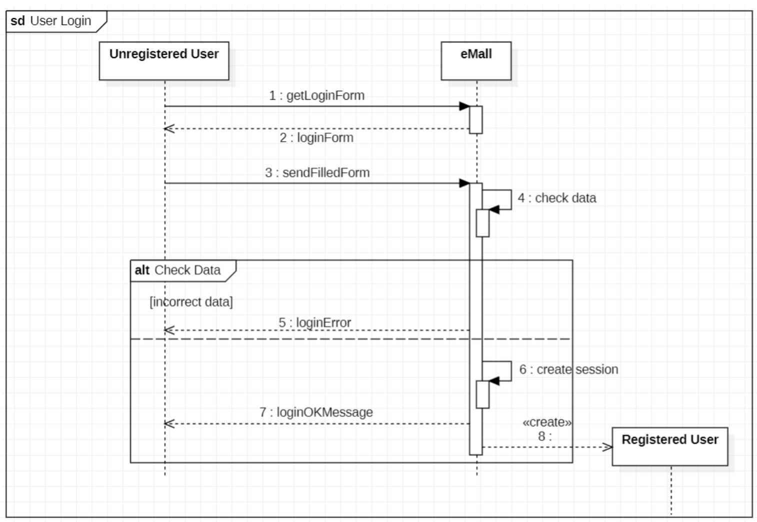

Figure 15: The above diagram shows the Sequence Diagram for User login

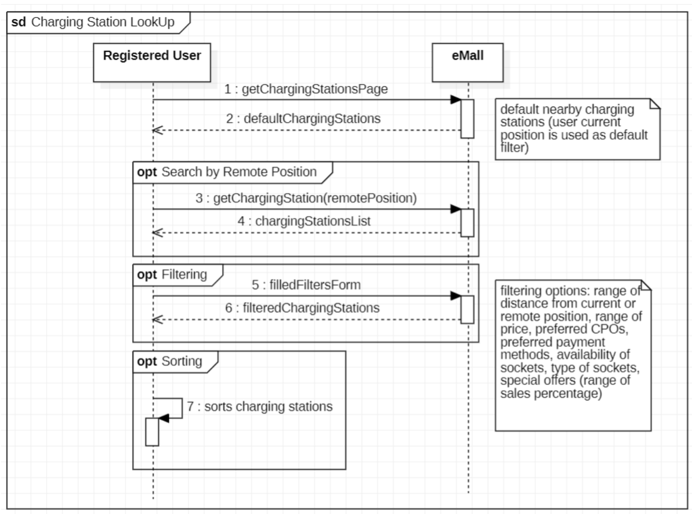

Figure 16: The above diagram shows the Sequence Diagram for a user wanting to look up for a charging station

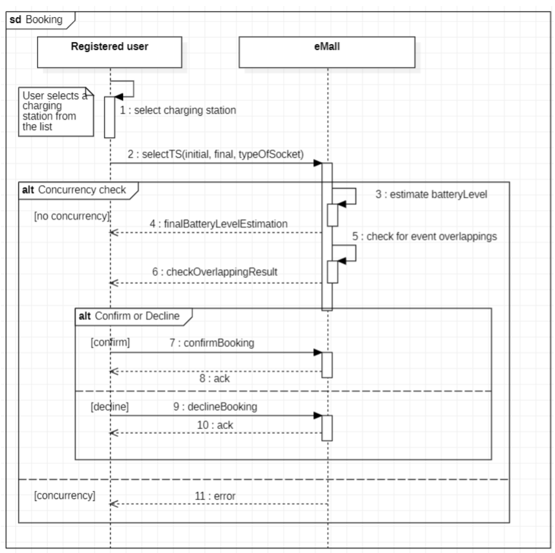

Figure 17: The above diagram shows the Sequence Diagram for a user wanting to book a charging station

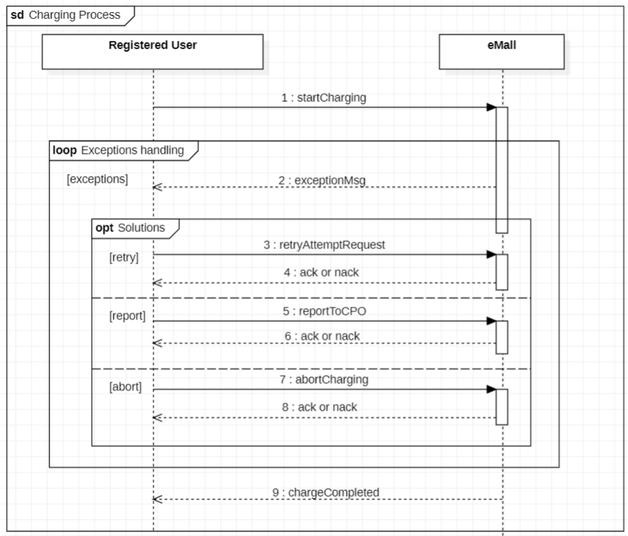

Figure 18: The above diagram shows the Sequence Diagram of an ongoing Charging Station

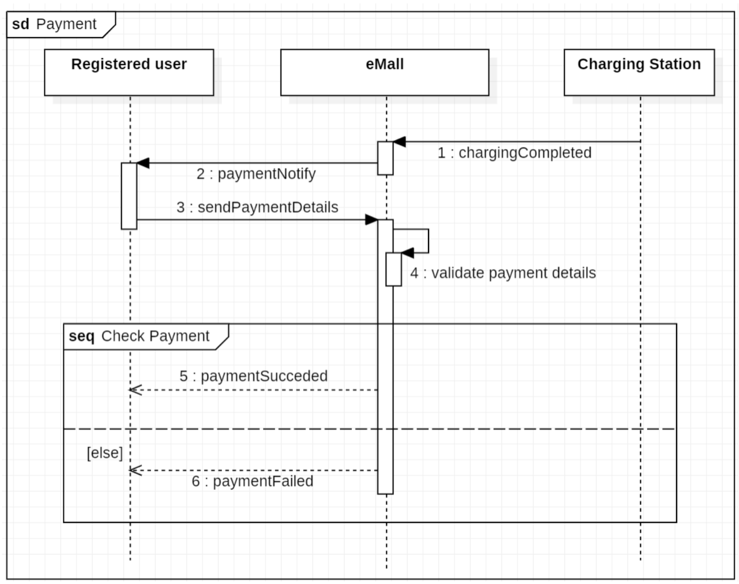

Figure 19: The above diagram shows the Sequence Diagram for a user paying for the used service

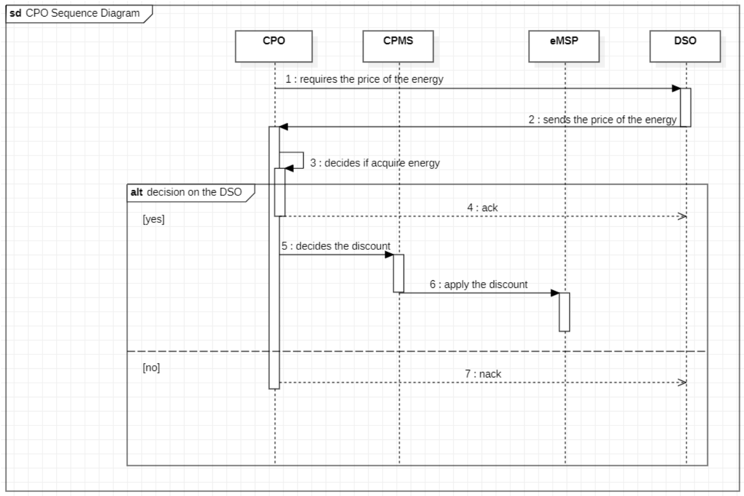

Figure 20: The above diagram shows the Sequence Diagram for a CPO

3.3 Performance Requirements

The system should always be available (24/7) and able to meet a demand of several simultaneously connected users (as we estimate to be around 1 million at most out of all 5.6 million EVs around the globe). It is possible to achieve this through redundant infrastructure and load balancing mechanisms that ensure server-side stability and scalability.

Since the user is connected to the system via mobile internet connection, communication problems may arise as a result of the user's mobility and low bandwidth (think of a user traveling to an area where there is little cellular coverage).

In order to make it possible to operate under precarious bandwidth and connection conditions, only essential information should be exchanged between client and server, and processing should be delegated to the business logic present on the client as much as possible. In more stable connection situations (home network or 5G), all nonessential synchronization operations can be performed.

3.4 Design Constraints

3.4.1 Standards Compliance

eMall must have compliance with current regulations in terms of data management and protection [1] Next, it must comply with all good practices for responsive and accessible design, with full support of the devices used by most users.

Thorough documentation should be provided for each component of the application explaining how that component can be extended and implemented. Obviously, this is extended to APIs meant to allow dialogue with CPMS and external providers such as authentication via public digital identity system (SPID or CIE), the DMV or the car manufacturer.

3.4.2 Hardware Limitations

It is possible to use the application from different types of devices: car infotainment systems, smartphone. The basic requirement is that there is a (hopefully stable) connection to the Internet, a GPS antenna to take advantage of the geo-location services, and that the device is working properly. An optional requirement is a fingerprint reader, which would make login and confirmation easier.

3.5 Software System Attributes

3.5.1 Reliability

The eMall system should be able to run continuously for a long time. If a system crashes frequently, even for a very short amount of time (e.g. milliseconds), it can be regarded as a very unreliable system and this is to be avoided by implementing fault tolerance, meaning that the system would provide its services even in presence of faults.

The key technique to mask a failure to the user is to apply redundancy, in particular, physical redundancy. In this case, a good choice is to adopt a COTS solution such as RAFT [2] within a redundant server processes group, characterized by a leader process with the ability to distribute the workload through the different replicated ones.

3.5.2 Availability

The eMall system has to be ready for use as soon as a user needs it to make a request. The goal is to have the highest availability possible. Statistics [3] state that there are over 5.6 million electric vehicles worldwide at the moment with a 64% increase, seeing total number of EVs rise from 3.4 million to 5.6 million in the last few years, number to be mapped to one possible eMall user and probably doomed to increase.

In order to provide system availability to so many users, the MTTR has to be automated through sophisticated recovery techniques. We deem that an availability of 99.9% (3-nines notation), equivalent to 8.76 hours/year downtime, should be enough to cover user's needs [4]. All the reasoning is assuming that communication links are reliable and remain so.

3.5.3 Security

The system is storing confidential information about user's movements and charging routines which could be exploited by external agents such as hackers or robbers.

This means that security has to be ensured by using passwords, bio-metric authentication, authorization methods, firewalls and encryption. In fact, the system must be closed, meaning that nobody can access it without passing the already defined access rules, managed by several deployed firewalls throughout the system.

3.5.4 Maintainability

The eMall system has to be open to various updates during its life-cycle as new features may be implemented or existing ones fixed. Software architectural patterns have to be chosen wisely to ensure decoupling between components in order to facilitate maintainability in accordance with prescribed procedures. This would smooth the path to restore a failed component within a specified period, fix a bug spotted within a certain component without affecting others, or enhance the software to provide new requested features.

3.5.5 Portability

The system should give the possibility to use the deployed platform in different environments and to different users. All heterogeneities must be covered as for Dev-ops, portability comes with stability.

The platform should not have different behaviours on different devices and should ensure consistency. For this case, the implementation could be done using Java Enterprise Edition (Java EE) in order to take advantage of all the functionalities it provides, along with high maintainability standards.

4 Formal analysis

4.0.1 Alloy

```
//signatures
    ↪ ----------------------------------------------------------------------------
    ↪

sig Email{}
//used for the fingerprint of the user
sig Byte{}
//is the Timestamp at which the user wants to book the charge
sig Date{
        year: one Int,
        month: one Int,
        day: one Int,
        hour: one Int,
        minute: one Int,
        second: one Int
}

sig User{
        userID: one Int,
        email: one Email,
        dateOfBirth: one Date,
        fingerprint:one Byte,
        type: one Type
}
//are the type of the User
abstract sig Type{}
one sig UNREGISTERED extends Type{}
one sig REGISTERED extends Type{}
one sig LOGGED extends Type{}

abstract sig Bool{}
one sig TRUE extends Bool{}
one sig FALSE extends Bool{}


sig VIN{}
sig Vehicle{
        vin: one VIN,
        user: one User,
        socketType: some SocketType,
        batteryLevel: one Int,
        typeOfBattery: one TypeOfBattery
}

//are the types of sockets available at the Charging Station
abstract sig SocketType{}
one sig FAST extends SocketType{}
one sig RAPID extends SocketType{}
one sig SLOW extends SocketType{}

//is the type of battery on the user's vehicle
sig TypeOfBattery{}

sig CPO{
        cpoID: one Int,
        specialOffer: some SpecialOffer,
        dso: some DSO
}

sig SpecialOffer{
        salePercentage: one Int
}
```

```
sig DSO{
        dsoID: one Int,
        costOfEnery: one Int,
        maxAmountOfEnergy: one Int,
        cpo: some CPO
}

sig ChargingStation{
        location: one Location,
        numberOfAvailableSockets: one Int,
        isActive: one Bool,
        cpo: one CPO,
        sockets: set Socket
}
sig Location{}
sig Battery{
        batteryID: one Int,
        isCharging: one Bool,
        availableEnergy: one Int,
        chargingstation: one ChargingStation
}
sig Socket{
        socketType: one SocketType,
        maxEnergyFlow: one Int,
        isAvailable: one Bool,
        costOfEnergy: one Int,
        vehicle: lone Vehicle,
        chargingstation: one ChargingStation
}

//is the reservation made to the User
sig Book{
        startTime: Date,
        endTime: Date,
        completed: Bool,
        bookStatus: BookStatus
}
sig BookStatus{}

//facts ------------------------------------------------------------------------------------

fact allUserHasVehicle{
        all u:User |
                ( some v:Vehicle | u.type = LOGGED ∧ u in v.user or u.type = REGISTERED ∧ u in v.user)
}

//each user must have a different email
fact distinctEmail{
        no disjoint u1, u2: User | u1.email = u2.email
}

//each user must have a different fingerprint
fact distinctByte{
        no disjoint u1, u2: User | u1.fingerprint = u2.fingerprint
}

//each user must have a different userid
fact distinctUserID{
        no disjoint u1, u2: User | u1.userID = u2.userID
}

//each charging station must have a different location
fact distinctLocationChargingStation{
        no disjoint c1, c2 : ChargingStation | c1.location = c2.location
}
```

```
//each vehicle must have a different VIN
fact distinctVIN{
        no disjoint v1, v2: Vehicle | v1.vin = v2.vin
}

//each user must have positive id
fact PositiveuserID{
        all u:User | u.userID ≥ 0
}

//each dso must have positive id
fact PositivedsoID{
        all d:DSO | d.dsoID ≥ 0
}

//each cpo must have positive id
fact PositivecpoID{
        all c:CPO | c.cpoID ≥ 0
}

//each battery must have positive id
fact PositivebatteryID{
        all b:Battery | b.batteryID ≥ 0
}

//each battery level must be positive
fact PositiveBatteryLevel{
        all v:Vehicle | v.batteryLevel ≥ 0
}

//each special price must be positive
fact PositiveSpecialPrice{
        all s:SpecialOffer | s.salePercentage>0
}

//each battery availability must have positive
fact PositiveAvailableEnergy{
        all b:Battery | b.availableEnergy ≥ 0
}

//each cost of energy must be positive
fact PositiveCostOfEnergy{
        all s:Socket | s.costOfEnergy > 0
}

//each charging station is active if at least one socket is available
fact ActiveChargingStation{
        all c:ChargingStation | c.isActive = TRUE iff (some s:Socket | s.
            ↪ isAvailable = TRUE and s in c.sockets)
}

fact VehicleConnectedToTheSocket{
        all s:Socket, v:Vehicle | s.vehicle = v iff (s.isAvailable = TRUE and
            ↪  v in s.vehicle)
}

fact SocketBelongsToASingleChargingStation{
        all s:Socket, c:ChargingStation | s in c.sockets iff c in s.
            ↪ chargingstation
}

fact OneSocketWithOnlyOneVehicle{
        no disjoint s1, s2 : Socket | s1.vehicle = s2.vehicle
}

fact DsoCpoRelation{
        all d:DSO, c:CPO | d in c.dso iff c in d.cpo
```

```
}

fact ConsistentDate{
        all b:Book | b.endTime.day > b.startTime.day and
                                        b.endTime.month > b.startTime.month
                                            ↪ and
                                        b.endTime.year > b.startTime.year and
                                        b.endTime.hour > b.startTime.hour and
                                        b.endTime.minute > b.startTime.minute
                                            ↪  and
                                        b.endTime.second > b.startTime.second
                                            ↪  and
                                        b.endTime.day ≥0 and
                                        b.endTime.month ≥0 and
                                        b.endTime.year ≥0 and
                                        b.endTime.hour ≥0 and
                                        b.endTime.minute ≥0 and
                                        b.endTime.second ≥0 and
                                        b.startTime.day ≥0 and
                                        b.startTime.month ≥0 and
                                        b.startTime.year ≥0 and
                                        b.startTime.hour ≥0 and
                                        b.startTime.minute ≥0 and
                                        b.startTime.second ≥0

}

//asserts
    ↪ --------------------------------------------------------------------------------
    ↪
assert EachChargingStationHasOnlyOneCPO{
        all c:ChargingStation| one p:CPO | p in c.cpo
}
check EachChargingStationHasOnlyOneCPO

assert UserCanHaveSomeVehicle{
        all u:User | some v:Vehicle | u in v.user
}
check UserCanHaveSomeVehicle

//predicates
    ↪ ---------------------------------------------------------------------------------
    ↪

pred show1{
        #User ≥2
        #Vehicle = 5
        #Book ≥ 2
        #ChargingStation > 1
        #Socket ≥ 3
}

pred show2{
        #CPO = 2
        #DSO = 3
}

run show1 for 5

run show2 for 3
```

4.1 First Model

In the first model we want to present focuses on the associations between users, vehicles, sockets, reservations(books), charging stations managed by CPOs and sockets. The following picture represents the show1 predicate in the alloy code.

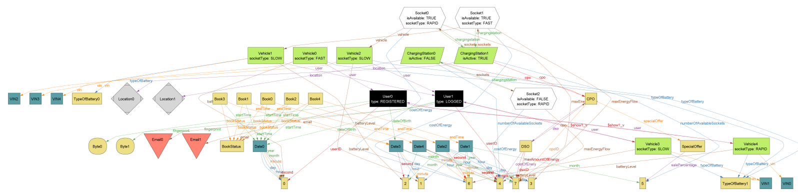

Figure 21: A predicate obtained for the first described model

4.2 Second Model

The second model focuses on the relationship between CPO, DSO, and charging sockets. The following picture represents the show2 predicate in the alloy code.

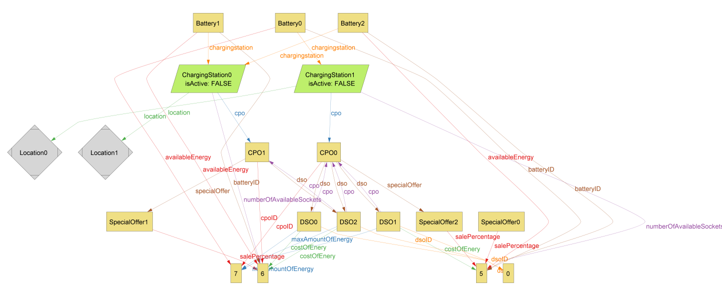

Figure 22: A predicate obtained for the second described model

5 Effort spent

5.1

Task	Time spent
Introduction	6 h
Overall Description	6 h
Specific Requirements	11h
Formal analysis	3 h
Convert Markdown to LaTeX	4 h

5.2

Task	Time spent
Introduction	4 h
Overall Description	9 h
Specific Requirements	10 h
Formal analysis	6 h
Convert Markdown to LaTeX	1 h

5.3

Task	Time spent
Introduction	6 h
Overall Description	7 h
Specific Requirements	10 h
Formal analysis	3 h
Convert Markdown to LaTeX	4 h

6 References

References

[1] European Parliament and Council of the European Union *Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation)* OJ L 119, 4.5.2016, p. 1–88

[2] Diego Ongaro and John Ousterhou *In Search of an Understandable Consensus Algorithm*, Stanford University

[3] Alex Kopestinsky *Electric Car Statistics In The US And Abroad*

[4] Richard Denning *Applied R&M Manual for Defence Systems*, Chapter 6: Probabilistic R&M Parameters and Redundancy Calculations