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INFORMATION SYSTEM DEVELOPMENT OF ELECTRIC CAR CHARGING STATIONS BY UNIFIED MODELLING LANGUAGE DIAGRAMS

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This paper presents a high-level approach to developing an information system for electric car charging stations, utilizing a Process Layer Supply pattern. This pattern organizes activity processes, business rules, visions, and goals that support system modelling. The paper models the system's structural and behavioral aspects using UML diagrams—specifically, class, use case, and activity diagrams — via the Papyrus UML2 tool. These diagrams facilitate visualizing functional requirements, user-to-system interactions, and system components for efficient planning, development, and implementation. The model addresses the most critical gaps in an electric car charging infrastructure and optimizes the information system's operations for practical implementation. The proposed system is designed to support future developments, like integration with dynamic demand markets for flexible pricing and optimized operations. Additionally, we use pseudocode to link abstract UML models to actual implementations, ensuring the accurate transfer of system logic to the corresponding code. Since every component of the charging network is logically interconnected, a sustainable foundation for future electric car mobility is established.

1. INTRODUCTION

In smart cities, the European Green Deal promotes the development of sustainable transportation through electric vehicles, integrated public transportation systems, and new technologies that enhance quality of life and reduce pollution [1-3]. Our innovative approach provides a roadmap for achieving these goals and expanding eco-friendly transportation through electric vehicles. Electric mobility is a significant trend in Serbia and beyond, driven by the emphasis on charging electric vehicles with renewable energy, which aligns with international sustainability and emissions-reduction targets [4].

Requirements analysis and design are now crucial in all engineering development processes, especially within information systems. Even limited standardised notations and techniques adequately address the specific needs for visualising and analysing both functional and non-functional requirements [5]. User requirements notation (URN) specifies high-level business requirements and goals. It uses goal-oriented requirement language (GRL) for modelling goals and their relationships and UCM (use case maps) for modelling usage scenarios [6, 7]. The novelty of our research lies in integrating UML diagram methodology with the process layer supply pattern to develop a model that visualizes system requirements and directly informs implementation logic through pseudocode and simulation. Specific, concrete measures enable a structured transition from the conceptual design stage to the stage of executable code. This imparts some pragmatic value in developing systems for charging electric vehicles. The transition from URN to unified modeling language (UML) diagrams is a significant step in the system's development process. It involves several steps, from basic requirements to the creation of various diagrams that provide a comprehensive overview of the system, as explained in Section 2. Also, the UML specification will serve as a basis for a possible information system of an electric car (EC) charging station network [8]. Several types of UML diagrams present the information system concept in Section 3. This study employed UML diagrams to elucidate the relationship between the information system concept and the pattern design process. By modelling concrete EV charging scenarios through Use case, activity, and class diagrams, we demonstrate how our system addresses real-world challenges, such as reducing waiting times and enabling online electricity purchases in Section 4. Section 5 describes the process layer supply business forms for organising processes, business rules, visions, and goals. Section 6 presents the conclusion of this study and consideration of future work.

2. LITERATURE REVIEW

According to Kumar et al. [9], prior studies on electric vehicle (EV) charging stations have primarily focused on technical factors, such as charger types, charging speeds, and the geographic distribution of charging stations.

Researchers have described numerous models for planning, designing, and locating charging infrastructure (CI) in the literature [10]. These models estimate the number of required charging stations at national or local levels to meet future demand and often use GPS driving patterns or mathematical models to determine the optimal distribution of charging stations, as proposed by Lin et al. [11].

Mastoi et al. [12] discuss the planning, technological developments, and optimal placement of electric vehicle charging stations. They review the current EV scenario, grid integration impacts, and the challenges and benefits of adopting and standardizing CI while exploring future trends like renewable energy procurement and vehicle-to-grid technology benefits.

Liu [13] initially analyzed CI assignments for the early EV market in Beijing, considering petrol refuelling stations, parking lots, transmission stations, refuelling behaviour, and residential data. Both slow and fast CIs, including battery exchange, are conceptualized to minimize the number of charging stations, with some models focusing on maximizing covered demand based on employment and residential data. Zhang [14] also employs regression and optimization models to estimate and maximize charging demand coverage in specific areas.

Besides these advances, there is a notable gap in

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considering integrated information systems that can manage and coordinate various components of the charging network. Most models focus on the initial roll-out of CI and do not account for real-life utilization data [15]. The adoption of plug-in electric vehicles is constrained by insufficient public CI, with the need for such infrastructure varying significantly across countries due to differing framework conditions such as home charging availability; however, Funke et al. [16] show there is a scarcity of studies that comprehensively analyze these medium- to long-term infrastructure requirements, and their findings are not universally applicable across all countries.

Accurate utilization data is crucial for CI developers to make informed decisions on expanding charging points [17]. The Amsterdam University of Applied Sciences has developed an assessment platform that processes and represents real-life charging data. This platform allows stakeholders to make informed decisions based on key performance indicators, summarized by Maase et al. [18].

This platform balances the need to promote zero-emission transport with limiting costly investments and has generalizable results applicable worldwide [19]. In the research of Hanni et al. [20], the gap underscores the need for a robust information system to improve user experience, reduce waiting times at charging stations, and optimize energy usage. While these studies provide a solid foundation in technical and infrastructural planning for EV charging systems, they seldom offer conceptualization for integrated information systems that handle user interfaces, operations, and business rules. Most contributions focus on physical deployment and grid integration without proposing structured, reusable system architectures that ensure consistency across software, data, and stakeholder perspectives. To address this shortcoming, our study proposes a modelling approach based on Unified Modeling Language (UML) integrated with the Process Layer Supply pattern. This combination aims to provide a system-level blueprint covering technical functionalities and business logic for a charging infrastructure network. The following section outlines the application of this methodology.

Developing an information system using UML diagrams provides a structured approach to address these challenges. Mohamed et al. explore the use of UML diagrams to model both the static and dynamic aspects of scalable information systems, demonstrating that UML provides a structural approach to viewing and handling system complexity [21].

3. UML DIAGRAMS

UML specifies, visualizes, constructs, and documents the development of software systems. The primary objectives are to increase productivity, decrease development time, and enhance software quality. UML is, however, not a development method but a modelling language based on the object-oriented principle and can be integrated well with various development methods. That proves to be highly effective in iterative development processes that are product-based and architecture-driven, associated with them. UML provides a usage range from specifying requirements to testing systems concerning the articulation of the static environment and dynamic behaviors of the information systems subject. In the context of this paper, at every step of development concerning UML diagrams, these diagrams structure the course towards visualising and managing system complexity. They are quite significant in terms of the design and function of information systems for electric car charging stations, which is the primary focus of this paper. The modelling approach utilised in the given study follows a structured sequence, beginning with gathering system requirements and progressing through scenario formation, UML diagrams, and implementation planning with pseudocode. A flowchart of the modelling processes can be found in Figure 1. It shows the logical steps involved in developing the structural and behavioural viewpoints of the system. Every stage helps create an architecture that is traceable and ready for implementation, bridging the gap between abstract models and actual software deployment.

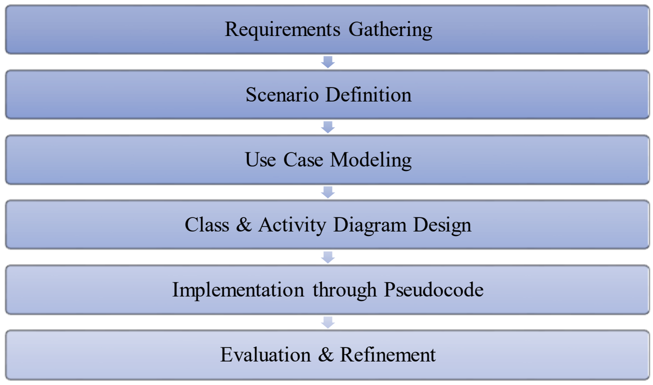

Fig. 1 – UML-based system modeling process flowchart.

The following steps outline the process for creating various UML diagrams, including Use Case, Activity, and Class diagrams [22].

Use case diagrams to depict the system's functional needs and describe interactions between actors and the system.

1. Identify actors: Identify all actors that will interact with the system.
2. Define use cases: Define various use cases based on the system requirements.
3. Create a Use Case Diagram: Show all actors and their interactions with the system using use cases.

Class diagrams illustrate the system's structural components.

1. Identify entities and their attributes: Determine the primary entities and their corresponding characteristics according to the system requirements.
2. Define relationships between classes: Map relationships and associations between entities based on requirements and use case scenarios.
3. Create a Class Diagram: Display entities, their attributes, and the relationships between them.

Activity diagrams represent the flows of activities and processes within the system.

1. Identify the main activities and flows: Map business processes and the main activities of the system.
2. Create an Activity Diagram: Show the sequence of activities, branching, and control flows in the system.

These procedures guarantee a seamless transfer from the original specifications to a thorough and organized system representation using UML diagrams. It is recommended to use tools that support both UML and URN when considering transformation facilitation. For URN, jUCMNav is used to model URN diagrams, while for UML, the Papyrus tool is used. For example, each use case in UML corresponds to a scenario in UCM, and all business goals, processes, and actors in the UML diagrams are covered in the GRL diagrams [23]. Papyrus provides support for UML profiles and is part of the Papyrus project. A UML diagram provides a high-level visual representation of a system, facilitating a comprehensive understanding of its architecture and the relationships between its various components [24].

After establishing the modelling approach, we shift the focus in the following sections from methodology to the specific system architecture and its components, which are developed through UML diagrams and supported by pseudocode.

4. DESIGN MODEL

In the context of this study, the described methodology enabled us to model three typical scenarios of user interaction with the EV charging infrastructure: on-site energy purchase, web-based charging reservation, and advertisement request processing. The resulting diagrams reflect both the structural and behavioral dimensions of the system and serve as a formal foundation for subsequent implementation and performance evaluation. The functional architecture of the system is depicted in Figure 2 (Use Case Diagram), which outlines the main actors and their interactions with the electric car charging system through key use cases.

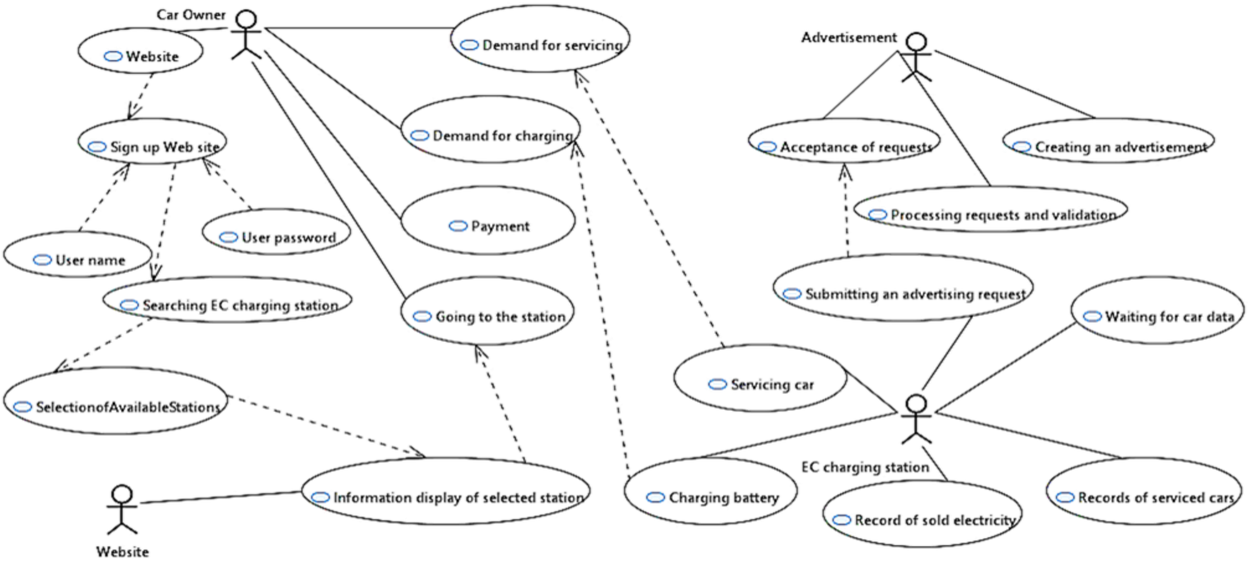

Fig. 2 – Use case diagram.

Activity diagrams were used not only to visualize workflows but also to define backend service logic in the implementation phase. Figure 3 presents the activity flow for purchasing electricity at the station, detailing the user decision points and system actions taken during the charging process.

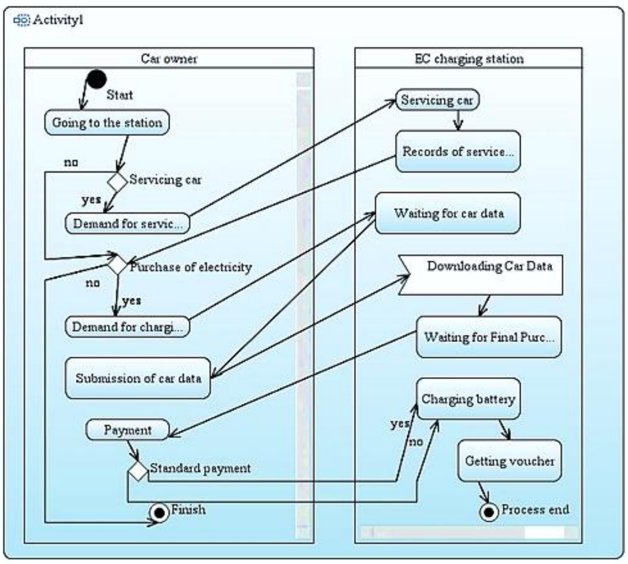

Fig. 3 – Activity diagram: purchase of electricity going to the station.

The process of purchasing electricity via the website, including user authentication and transaction steps, is shown in Fig. 4.

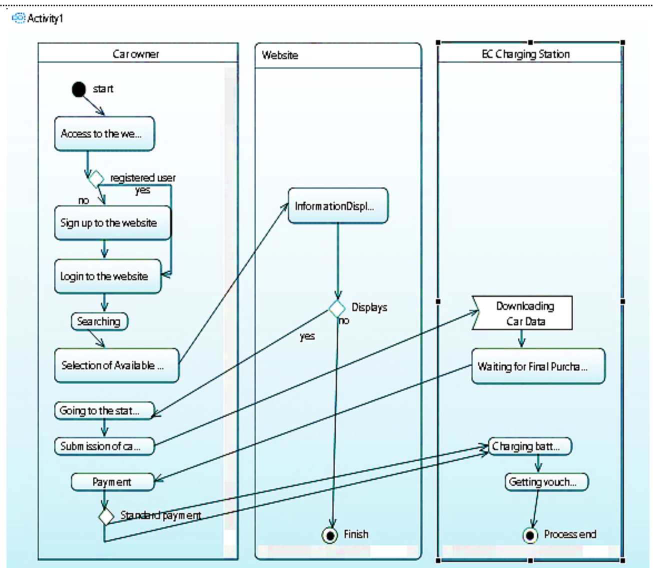

Fig. 4 – Activity diagram: *Purchase of electricity using a Website*.

This flow was implemented using a sequence of modular service calls for user validation, station lookup, and transaction processing. The diagram served as a guide for service orchestration and user interface behavior.

Figure 5 displays the workflow for managing advertisement requests at the charging station, from submission to advertisement creation. Each activity was transformed into a method or microservice endpoint, enabling modular execution and maintainability of the advertising component.

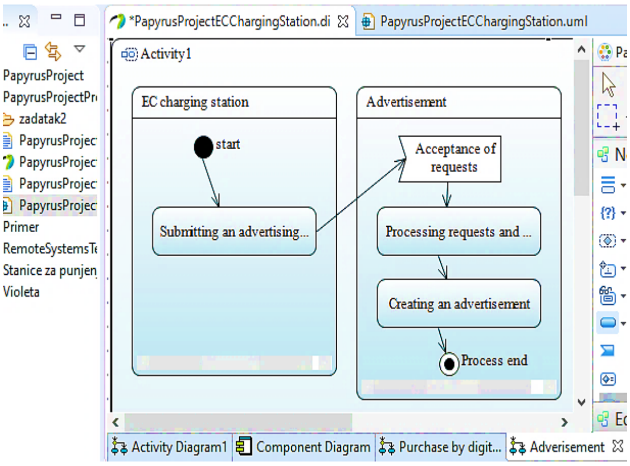

Fig. 5 – Activity diagram advertisement.

A UML representation of a class in a class diagram has three parts: the upper part indicates the class's name, the middle part specifies its attributes, and the lower part indicates the methods. The structural relationships among core system components, including classes, attributes, and operations, are depicted in Figure 6.

These structures directly informed the database schema and backend code, where classes like *CarOwner*, *ECChargingStation*, and Advertisement were implemented as software modules with properties and methods corresponding to those in the diagram. For numerous reasons, it is crucial to utilise UML diagrams and pseudocode when developing complex systems, like an information system for electric vehicle charging stations.

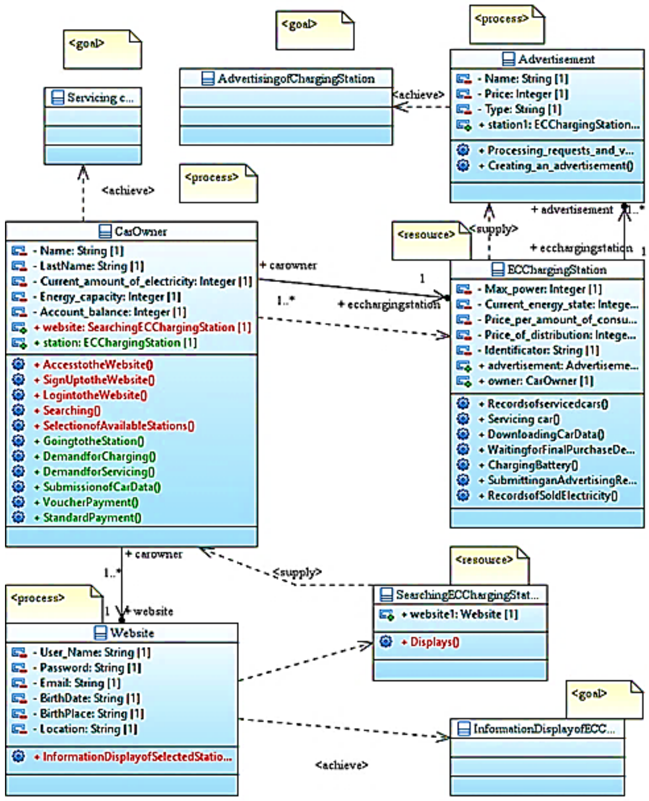

Fig. 6 - UML class diagram.

However, as shown in Fig. 7, pseudocode helps translate these abstract models into a more concrete format, assisting in the transition from design to operation. The pseudocode allowed developers to prototype class behavior before writing production code, ensuring logical consistency with the model.

To support implementation, Fig. 7 provides the pseudocode translation of the CarOwner class, aligning with the relationships defined in the class diagram. This helped ensure alignment between conceptual structure and software logic during development.

```
CLASS CarOwner
    ATTRIBUTES:
        Name: String
        LastName: String
        Current_amount_of_electricity: Integer
        Energy_capacity: Integer
        Account_balance: Integer
        website: SearchingECChargingStation  # Represents an association with the SearchingECChargingStation class
        station: ECChargingStation  # Represents an association with the ECChargingStation class

    METHODS:
        AccessToTheWebsite()  # CarOwner interacts with the Website through this method
        SignUpToTheWebsite()  # Sign-up process via the Website
        LoginToTheWebsite()  # Login process for authentication
        Searching()  # Method to search for available charging stations
        SelectionOfAvailableStations()  # CarOwner selects an available station
        GoToTheStation()  # Method to proceed to the selected charging station
        DemandForCharging()  # Request to charge the car at the station
        DemandForServicing()  # Request for servicing the car at the station
        SubmissionOfCarData()  # Submitting car-related data to the charging station
        VoucherPayment()  # Handling payment via vouchers
        StandardPayment()  # Handling standard payment methods

END CLASS
```

Fig. 7 - Pseudocode class CarOwner.

5. DISCUSSION

The activity diagram of the *Purchase of electricity going to the station* (Fig. 3) shows how various processes occur depending on the different user requests of a car owner. On arrival, the system will assess whether the car is a service case. If there is a backlog, the system adds the car to the service queue; otherwise, it directs the car to an electricity purchase. Such a dual-mode simplifies the operations of a charging station, as it can serve both types of customers. Similarly, the activity diagram for *Purchasing electricity using the Website* (Fig. 4) shows the branch of action after determining whether the user is registered. After determining this, an action can be taken to log in to the user or address other issues concerning station identification, culminating in the purchase action. The two diagrams thus show agility and customer orientation in the system aimed at reducing waiting times while maximizing energy use.

The *Advertisement* activity diagram, shown in Fig. 5, illustrates the workflow for the EC charging station actor. After the *Submitting Advertising Requests* activity, an Accept Event Action node is created. The request is sent to an already engaged advertiser, creating two opaque action nodes: processing the request, checking its correctness, and creating the Advertisement itself.

Pseudocode is a step in between the execution of a specific language and the abstract models in UML. Once the pseudocode has been approved or revised, it is superficial to translate it into an implementation in a particular programming language while maintaining the desired system logic.

In the *CarOwner* class, the website attribute is associated with the *SearchingECChargingStation* class, corresponding to the relationship shown in the UML class diagram.

Additionally, comments like # Represent an association with the *ECChargingStation* class, explaining how the station attribute in the *CarOwner* class is connected to the *ECChargingStation* class, thereby reflecting the associations depicted in the UML diagram. Comments next to methods describe what each method does based on the processes and actions indicated in the class diagram. Figure 8 illustrates the Process Layer Supply model applied in this study, visually mapping the flow of business processes, states, and operational logic.

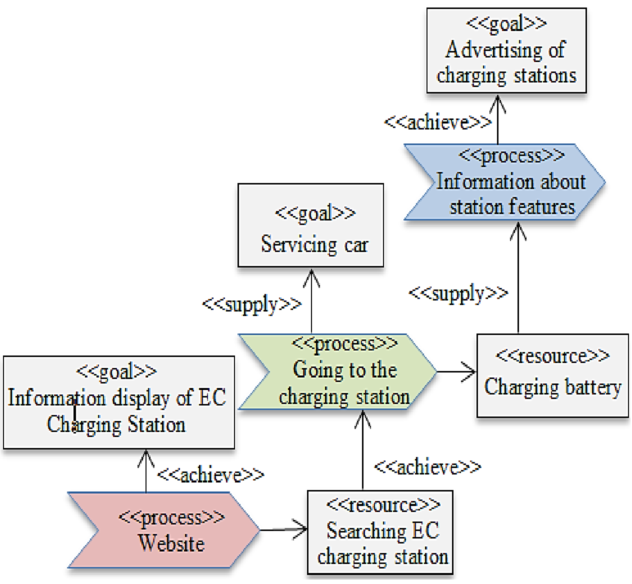

Fig. 8 – Process layer supply.

The previous figure uniquely characterises each state in the diagram with different colours, which helps differentiate the functional aspects of the information system. The purpose of this diagram is to illustrate how the system handles business rules and procedures.

Although the current model covers fundamental user-service interactions, it does not include advanced capabilities like real-time analytics, adaptive pricing, and grid-level integration. We purposefully chose this abstraction so that we could concentrate on the modularity and clarity of the system. The modelling and documentation represent a scalable system design that synchronises stakeholder objectives with system logic. In order to improve sustainability and deployment readiness, future work will expand class and activity diagrams to enhance predictive capabilities and smart grid integration.

6. CONCLUSION

This study examines trends in electric mobility and fosters the growth of electric vehicle charging infrastructure in urban areas. It underscores the significance of information systems in solving the problems caused by the integration of "smart" mobility solutions. An exquisitely designed structure and implementation framework for the EC charging system captures UML diagrams and pseudocode. System interaction is ensured to be open-ended through functional requirements that are accurately specified and implemented in functional applications. The architecture optimizes flexibility and scalability for future development, optimizing electric mobility and translating it into Process Layer Supply patterns.

Advanced capabilities, such as real-time analytics, adaptive pricing, and grid-level integration, are not included in the current model despite its coverage of fundamental user-service interactions. We purposefully chose this abstraction so that we could concentrate on the modularity and clarity of the system. The documentation and formal modelling represent a structured, scalable approach to system development, aligning stakeholder goals and technical components. Future work will extend the class and activity diagrams to support predictive logic and integration with innovative grid systems.

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Violeta Dimić: Conceptualization, methodology, validation, writing—original draft preparation, supervision.
Predrag Milošević: Software, investigation, visualization, and funding acquisition.
Zorica Đurić: Conceptualization, validation, project administration.
Aleksandar Stokić: Resources, writing, review, and editing.
Vojkan Nikolić: Formal analysis.

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APPENDIX

Figure A1 provides the Python code developed in the study.

```python
class CarOwner:
    def __init__(self, name, lastname, electricity, capacity, balance):
        self.name = name
        self.lastname = lastname
        self.current_amount_of_electricity = electricity
        self.energy_capacity = capacity
        self.account_balance = balance

    def access_to_website(self):
        # Logic for accessing the website
        pass

    def sign_up_to_website(self):
        # Logic for signing up to the website
        pass

    def login_to_website(self):
        # Logic for logging into the website
        pass

    def searching(self):
        # Logic for searching charging stations
        pass

    def select_station(self):
        # Logic for selecting an available station
        pass
```

Fig. A1 – Code in Python.

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