Versatile Car Sharing Modelling for Sustainable Mobility with Embedded Intelligent Modules

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ABSTRACT

The continuous growth of the population in the cities has caused several problems in the urban mobility worldwide. Sustainable mobility is in the center of the strategy that challenges the current situation in the transportation systems which are mainly based on private cars. MaaS, a concept that gains ground on the mobility problems, holds a key role on the transition towards a sustainable mobility era. The sustainable city of the future will offer flexible, optimized and personalized transport solutions to travelers, based on the principles of MaaS, on a daily basis. Travelers will have the option to choose shared mobility solutions instead of owing a car. Today there are plenty of technologies and apps offering MaaS solutions. Yet, their effectiveness and the users' acceptance are still premature. In this paper we describe a complete s/w interface, named as Need4Car, which supports car sharing solutions of any type, as a part of a MaaS system, for any fleet of any kind of operator (rental companies, car dealers, municipalities etc). The platform serves a large set of car sharing features related with data from vehicles, users, transactions management as well as fleet management components. It also contains tools for analysis and visualization of the data and modules based on machine learning approaches to support management decision. Driving behavior module is presented in this paper as an AI module of the platform. More AI tools can be easily added and integrated using the options of the system and especially the administrative dashboard. The whole system stands today as a product in the mobility market with various customers form different countries in the globe.

KEYWORDS

Car sharing, MaaS, Smart mobility, Sustainable mobility, Smart city, AI for mobility, Driving behavior, Electric Car Sharing, Decision Support System for mobility

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1 INTRODUCTION

The rapid influx of people into urban areas has caused negative environmental impacts and several mobility problems such as traffic congestion, CO2 emissions, the shortage of parking areas, etc [1],[2]. These problems can be solved with the adaptation of new mobility solutions which play a key role in the economic, social and environmental dimensions of the cities [3]. "Mobility as a Service" (MaaS) has emerged as a concept aiming to deliver users' transport needs by combining various forms of transport services into one service, providing an alternative to car ownership [4]. MaaS solutions can be effective only if they manage to improve the sustainability of mobility especially in densely populated areas [5].

Research in mobility today is similarly directed to the problems of the highly congested cities, the Strategies that should be adopted for sustainable urban environment in order to meet the increased demand. A commonly identified factor that has a fair share to the negative environmental impact in the contemporary urban areas is the car ownership. Private cars are proved to be of the most environmentally harmful means of mobility [9]. MaaS options introduced car sharing models as an alternative choice to private mobility and according to [8] one station-based car sharing vehicle is associated with a reduction of about nine private cars.

Additionally, the expansion of car sharing in recent years and especially the inclusion of electric vehicles in the fleet, made this sharing option favorable to the public [12]. Car sharing offered models are usually related to the pickup / return location of the vehicle: a) the free floating model is offered when the drivers locate the vehicle at any on-street parking space of the city and they can have a one-way or a round trip and b) the station based model is offered when the drivers pick/up and return the vehicles at predefined spaces by the provider. Now car-sharing is experiencing considerable growth worldwide. Indicatively, the number of registered users in Germany has increased more than 15-fold in the past ten years and the number of shared cars has increased more than five-fold [11]. Yet its positive impact is under research through deep learning technologies

The expansion of the ICT technologies along with the demand for either web of smartphones' apps brought features of great flexibility, effectiveness, convenience and agility to their customers [13]. Therefore, deep learning and AI technologies will drive the future mobility trends and more specifically the design, planning and operability of the mobility systems. Many studies in the literature are focused in analyzing the objective data gathered from real car sharing cases, eg demographic information, car sharing users' density, etc [6]. Yet, limited research is found in analyzing the relation between travelers' behavior and car sharing use [7]

The development of computational tools using sensor measurements for the analysis of data acquired by vehicles along with the preferences and the habits of the users of car sharing services create challenges to use AI tools and analysis features for different scopes. Such scopes include but are not limited to support decision of market opportunities, provide operator a better determination of station or parking places without affecting the revenue plans or distributing too many vehicles in one area. Scoring the driving habits of the users of shared vehicles brings significant information in two levels: a) the providers need to manage the value of the fleet by eliminating possible accidents or poor use of the vehicles and b) the drivers need to get live feedback for their driving score in order to ensure safety on the road from a non-owned vehicle. Fleet owners having a ranking of the drivers based on their driving behavior score can reward the drivers to future trips. Machine learning approaches address objective and equal classification of the scoring helping operators to better manage and optimize the assets

In this work, we introduce a complete car sharing platform, named Need4Car, consisted of 3 applications (mobile-web-operator's/administrative dashboard). It is a fully customizable platform to any operator's requirements. An extensive set of features to realize any car sharing service is included, starting from vehicles and users management, to complete transactions (payments) interface up to detailed analytics based either on built-in / ready to use KPIs or new KPIs designed by each operator that can be easily imported to the system. A significant advantage of the platform is the integration of machine learning procedures as external modules based on the data acquired / stored in the corresponding system's architecture. A driving behavior classification tool is presented, as an example, of the integration of AI tools and modules to the platform of Need4Car.This approach is based on NN-based encoding and rule-based event detection for the classification of the overall driving behavior into three classes as aggressive, semi-aggressive and normal driving

The rest of this paper is organized as follows: in sect. 2, we describe the entities and the architectural approach of the system along with the principles of Neural Networks used for the driving behavior classification. In sect. 3 we present the functional diagrams of the entities and the flow of the information along with a representative set of built-in features. sect 4, contains description of results of the platform as this is used today in different operators' business cases. Some representative classification results on existing trips are also included in this section. In sect. 5 we discuss the main conclusions of this work and the future challenges of car sharing mobility.

2 ENTITIES AND THE ARCHITECTURAL APPROACH

From a software standpoint, the system is comprised of various entities that cover the operational needs of the linked applications. Each entity contains information for different parts of the applications and are usually interlinked with each other.

One of the main entities is the Vehicle entity that represents the actual vehicle that will be used for reservations from any user. An external telematics device is usually installed in order to provide the application with the necessary data such as the lock/unlock state as well as CAN bus data. Either electric, hybrid or conventional vehicles are supported.

The Vehicle entity is related to a Pricing Model which dictates the usage costs of that vehicle during a reservation. Defines the relevant costs that are used to calculate the final price of the reservation. A pricing model is tied to a vehicle and except for the basic per minute/hour/day costs, it contains extra costs or flags that are added or activate during the course of the reservation. For example, there is an option to set an overnight rate, which is a fixed cost that applies using during night-time and it is configurable by the administrator.

Based on the reservation model that each vehicle is configured, either free-floating or station-based, an extra layer of management may be needed. In case of a free-floating approach, a Vehicle could be related to a Geofence, a virtual perimeter for a geographic area. It can be either a polygon or a circle. It is usually used to trigger events during the crossing of the geofence area as well as provide semantic information about the whereabouts of the vehicle.

On the other hand, for a station-based scenario, The Station entity covers the business needs and goes hand to hand with the Geofence entity, meaning that a Geofence is used to define the geographic area that a Station covers. The actual Station can be inferred as a POI (Point Of Interest) which, business-wise, adds an extra functionality that is grouping vehicles under a specific geographic location, such as a parking area or a gas station. Any vehicle reserved from a station needs to be parked in the same or another station.

Any vehicles are not directly linked to the users of the application but are related through the Reservation entity. Any user that registers to use the application is represented via this entity. Apart from some basic data (username, password, phones, addresses etc.) that are handled, there are also some extra information that are needed such as identity and driver license as well as financial information that can be used when integrating with third-party payment gateways (Viva Wallet, Cardlink, PayPal etc.).

The Member entity is related to the Customer entity that contains additional information such as billing/shipping addresses and phone numbers. It also adds an extra layer above the member by having a 1-to-N relationship, meaning 1 customer linked to multiple members. This is especially useful when a registered user represents a company. Thus, the customer contains company details, and the member contains the user personal details.

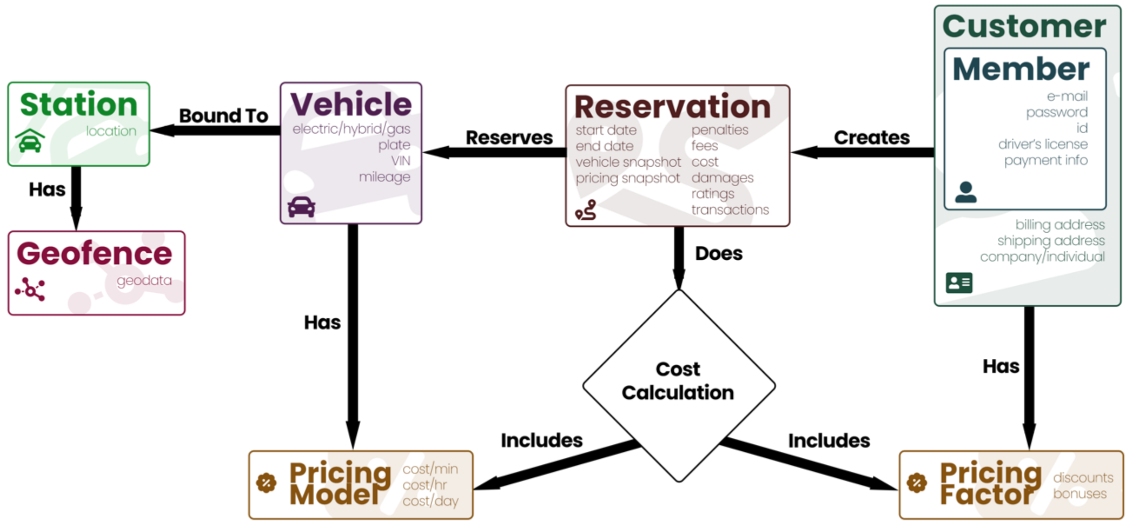

Figure 1: Entities relation diagram

Both the Member and Customer entities are linked to the Pricing Factor entity. Shortly, a pricing factor defines discounts and bonuses for use during a reservation and affect its overall cost. Any member or customer can be assigned to a pricing factor. Due to the fact that a customer can be of type “company”, a discount will be applied to all members linked to that customer.

The most important entity that is interlinked with most of the previously described entities is the Reservation entity. It contains details about the reservation that the user creates such as start/end time and several other key timestamps, fuel and odometer readings from the vehicle (as historic data for calculation reasons) and part of pricing values.

Except the main relations this entity has, there are a few of them that contain additional information for any post-reservation calculation as well as for reporting purposes. The main ones are the cost analysis, containing any intermediate calculation values based on the final cost of the reservation which are saved for historic purposes, penalties/fees, car damages/images submitted by the user before and after the completion of the reservation as well as rating details which is quality assessment of the reservation submitted by the user.

Since the system is connected to third-party payment gateways, in order to cover the invoicing process, transactional records that are produced from reservations or other extra costs such as penalties are saved at the Transaction entity. Apart from the provider’s specific data, a generated PDF file containing invoicing and reservation information, much like a receipt, is also kept.

The following Figure 1 provides a visual approach of all the main entities linked with each other based on their relation.

2.1 Classification of the Driving Behavior

As mentioned above the platform supports the integration of modules that implements algorithms based on the processing of data maintained in the database of Need4Car’s architecture. An option that is presented in the following paragraph is a tool based on machine learning, especially on recurrent neural networks algorithm, to characterize/classify the driving behavior of the users. Recent advances in machine learning, which include several variants of recurrent neural networks (RNNs), could be valuable for the development of objective and efficient computational tools in this direction. RNNs, such as long short-term memory (LSTM) and gated recurrent unit (GRU) networks, are formulated to handle time-series data, as is the case with measurements obtained by telematics sensors, mobile phone sensors or on-board diagnostics (OBD) ports. The RNN-based variants (LSTM and GRU) directly process sensor measurements in the form of time-series [10].

3 FLOW OF THE INFORMATION - BUILT-IN FEATURES

The backbone of the service is the reservation flow. It interconnects all the previously described entities and along with the configured logic. All the integrated entities are related to the features offered by the platform. In the following paragraph the reservation feature is presented in details with the involved entities and the flow of the information needed.

3.1 Reservation procedure

At a high level, the user books a reservation with either a free-floating or station-based vehicle, verifies the reservation via a 4 digits PIN which is generated the moment a user registers at the

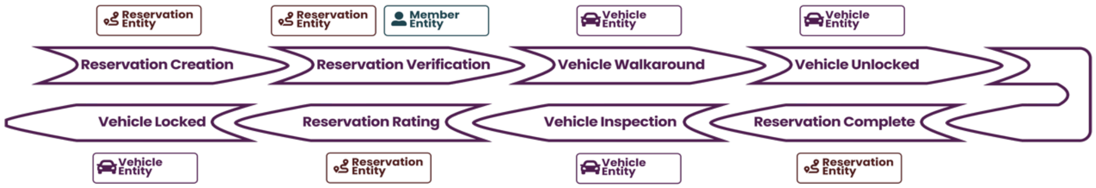

Figure 2: Reservation flow actions related to each Entity

application as well as posting any possible damages that may be present from a previous reservation. Then, the user unlocks the vehicle via the mobile application.

At this point the user is presented with a timer that shows the current duration of the reservation as well as the current reservation cost, which may be different from the final cost due to discounts or other expenses. At some point, the user concludes the reservation, paying the calculated final cost through the mobile application in a more or less seamless way, depending on the selected payment provider.

The final steps are the posting of any possible damages and the rating of the reservation experience as well as the locking of the vehicle. In case of emergency or inability to unlock or lock the vehicle via the mobile application, the back-office administrator has the possibility to send the relevant command to the vehicle.

Making a reservation requires some actions from the end user in order to effectively start using the application. Apart from the registration with a unique e-mail address and the verification of his/her account, the user needs to fill in a few details from his/her profile page using either the web or mobile applications. The main categories are the driver information, including driver license and identity, among other things, billing and shipping details as well as payment details for invoicing purposes.

Below, a brief diagram is provided with the main actions performed during the reservation process linked with their respective entities. In any case, all actions are related to the Reservation entity which contains most of the information. Each other entity provide specific data that are handled per action, such as the unlock/lock of the vehicle before/after the reservation, respectively, as shown in Figure 2.

The whole calculation of the reservation's final cost is based on a set of rules, an algorithm in essence, based on several variables and parameters, from the actual duration of the reservation, driven distance to fixed costs and discount, which are fully configurable by the administrator of the application. There are 3 main parts of calculations. Calculation of any costs before the main discounts, application of any discounts after calculating the main costs and calculation of any costs after the main discounts. Each part defines several other calculations based on each configured parameters and variables.

3.2 Calculate any costs before main discounts

The first and foremost important calculation is based on the duration of the reservation. The duration is split up to days, hours and minutes parts where each part is multiplied by its respective pricing model parameter in order to get the basic cost of the duration. Depending on the configuration, only one of the 3 parts may be calculated. During the registration process at the service, the user may receive bonus minutes or credits (in form of currency) as a gift that will be automatically redeemed from the final cost. The user has not interaction with them apart from monitoring them.

There are cases where the administrator may want to alter the cost of the reservation based on the duration or the time that the reservation is starting/ending. For the first scenario, a "day limit" parameter can be configured in order to check if the hour component of the current duration is greater than this value which, in turn will increase the day component, thus altering the cost of the reservation. In essence, this change will decrease the cost of the reservation since the day component will have a different cost from the hour component.

The second scenario is based on the start and end dates of the reservation and usually is configured to cover part of the afternoon and night times in order to encourage the user to keep the vehicle during the day and return it early in the morning. Usually, this scenario may cover employees that want to use a car to return back home and then use it again to get to work the next day. During this "overnight" period the cost of the reservation is fixed to a specific value. If the start/end dates are not inside this period the cost changes according to the basic rules.

There are also some forms of penalties that may occur due to the excess usage of the car during the reservation. In case the user keeps the car for a long period of time there might be extra fees applied regarding excess duration and distance. For any extra km or minute (in the case of duration) that occurred, a small charge is applied, thus increasing greatly the final cost of the reservation. These parameters are usually configured to discourage extensive usage of the vehicle during the reservation, mainly in terms of distance.

Regarding the fuel consumption during the reservation, the administrator has the possibility to configure a fuel delta parameter that will be applied in case the user returns the vehicle with less fuel that it contained in the beginning of the reservation. In conjunction with the refueling bonus, that is applied at the next part of the calculations, this process encourages the user to refill the vehicle (either it is electric/hybrid or conventional) in order to get an additional discount at the end of the reservation.

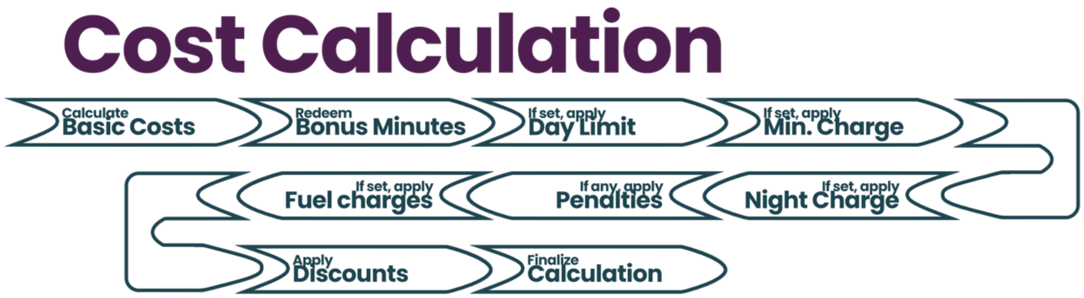

Figure 3: Pricing algorithm calculations flow

3.3 Apply any discounts after calculation the main costs

After most of the parameters have been calculated, any discounts that an administrator has configured are applied. These are the bonus credits that the user may have received during the registration process, any percentage discounts as well as the refueling bonus in case it can be applied, depending if the vehicle is returned with more fuel.

3.4 Calculate any costs after main discounts

After any discounts are applied the only possible additional costs are usually fees that are applied automatically, such as parking costs, but there are also cases where penalties can be applied manually by the administrator after the completion of the reservation via the backoffice application. These may include penalties for lost keys, unauthorized parking fees as well as internal or external damages of the vehicle after its inspection.

There are always scenarios where the final cost could be 0 (zero). Discounts that cover the whole cost of the reservation where the duration is small enough to be covered. A "zero cost" parameter was created that defines a fixed price that the user has to pay in case there is no cost for the reservation.

The following Figure 3 provides more details on pricing calculations.

3.5 RNN-based Time-series Representation

Datasets were acquired by means of telematics device. The device is equipped with accelerometers, a GPS receiver of 1 meter resolution and a GSM modem that works up to 4G cellular protocol. The raw accelerometer data were merged with the corresponding GPS coordinates to create vehicle routes. Each route sample has approximately a duration of 15 min, whereas the measurement vectors were acquired at 0.1 Hz and comprise 27 features: maximum positive acceleration, maximum negative acceleration, maximum transverse acceleration, a 21-bin histogram of acceleration values ranging from -0.5g to 0.5g, latitude, longitude and speed. Three types of driving behaviour have been considered: normal, semi-aggressive and aggressive.

RNNs such as LSTMs or GRUs are employed for the classification of time slices of raw acceleration data. The absolute classification accuracy is not a primary concern at this stage and the resulting time-series encoding represents the frequency of occurrence of driving patterns. Both LSTMs and GRUs are configured with 1 layer of 128 neurons, followed by a dense layer of 2 neurons with softmax activation function. This shallow network architecture has been tested, taking into account to avoid overfitting. Sparse categorical cross-entropy is employed as a loss function and Adam is employed for optimization.

3.6 RNN-based Time-series Representation

The histogram generated from the RNN-based component is concatenated with the one generated from the rule-guided component forming a feature vector aimed at reflecting overall driving behavior. This feature vector is divided by overall route duration and normalized. Labelled samples of normalized feature vectors are used to train a standard SVM classifier, in order to assess driving behavior in the route level.

4 RESULTS AND DISCUSSION

In the paragraph that follows is a description of a small set of the features and the options included in the whole platform of Need4Car along with some screen shots. Firstly, the system contains mobile and dashboard / administration applications as shown in Figure 4 that follows:

The Interface for the reservation procedure is presented in the following Figure 5 starting from the mobile application through which the user follows the steps to complete the reservation. These steps follow the reservation procedure flow of as described in sect. 3.

The next figure Figure 6 shows results of the classification of driving behavior of two different trips using the RNN algorithm and especially the LSTM and GRU methods as described in two previous sections. The different colors indicate different driving classes.

There many more options that can be shown with a numbers of parameters and results but such an extensive presentation is out of the scope of this submission. The whole system is ready to the market product with successful business installations in Greece, Germany, New Zealand and more.

5 CONCLUSIONS

The adaptation of sustainable transportation strategies in modern cities is of high importance and plays a key role in the everyday mobility habits of the citizens. MaaS places travelers' needs in the

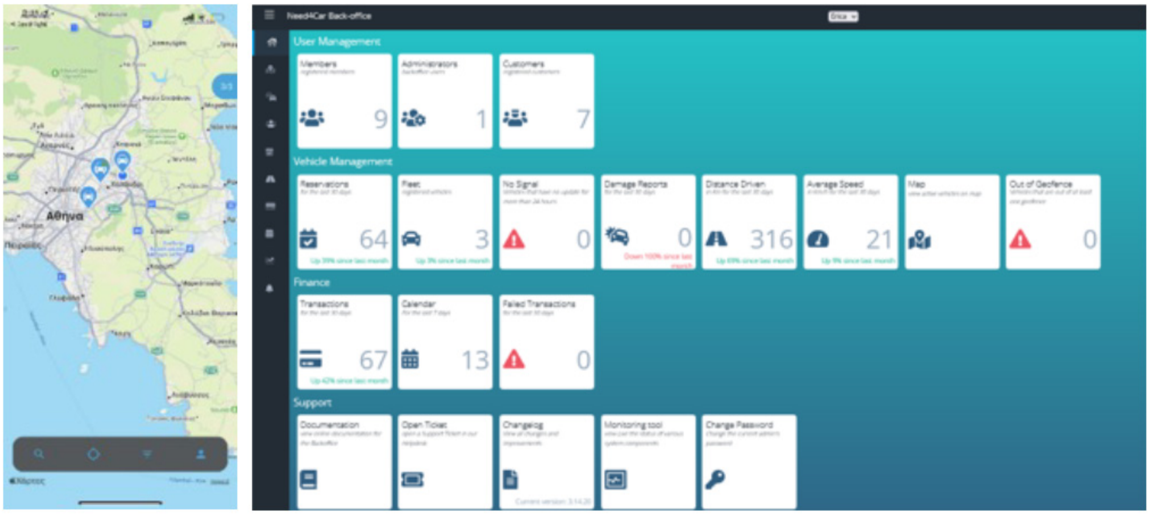

Figure 4: Mobile - dashboard / administration modules of Need4Car

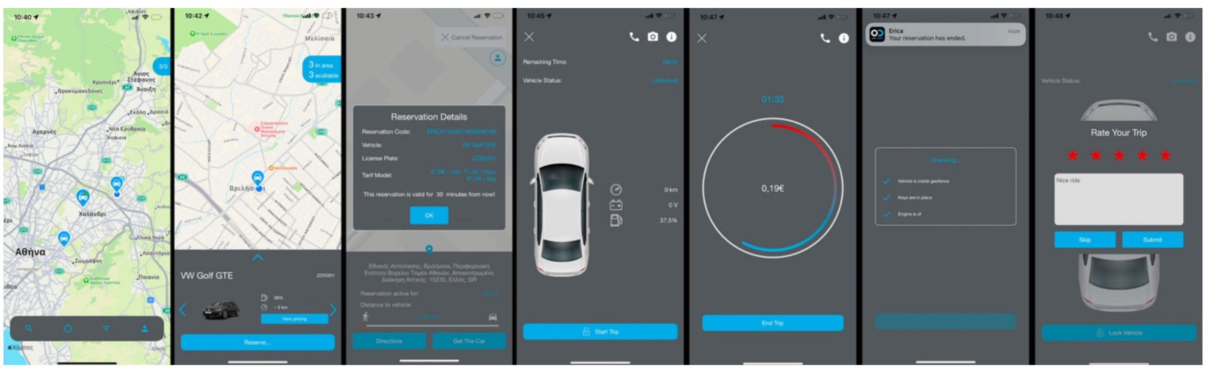

Figure 5: Reservation procedure of Need4Car using mobile

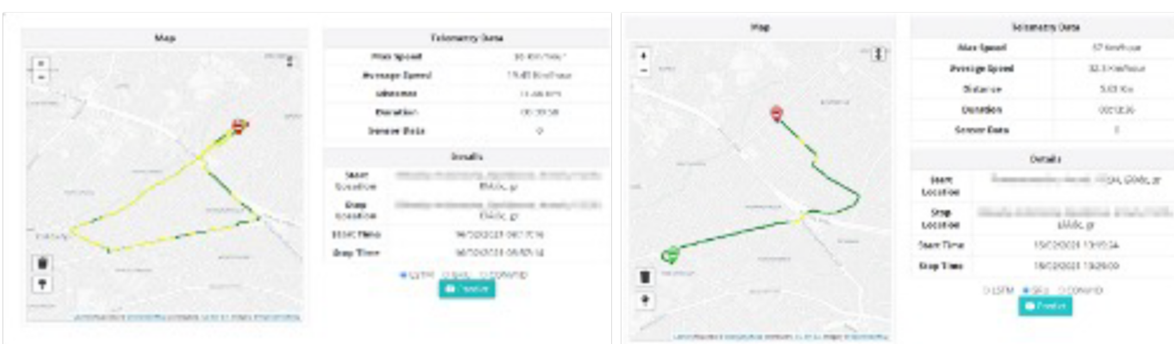

Figure 6: Classification of driving behavior of two different trips using LSTM and GRU algorithms (Green: normal driving, Yellow: semi-aggressive, Red:aggressive).

center of the new transportation policies offering flexible, environmental friendly and low cost sharing solutions in their daily mobility. Additionally, the extensive use of MaaS services creates a new culture of an equal, free and democratic transportation system. On that account, artificial intelligence (AI) technology is inevitable and remains as a component in any kind of mobility proposal. IT technology with its significant evolution has penetrated to everyday life of citizens, irrespective of age or social status. Car sharing, as a major component of MaaS, gains important advantages compared to the ownership of vehicles during the last 5-8 years. According to the results of real cases, a shared vehicle can contribute to the reduction of private cars in the city centers. Therefore, it contributes significantly to the elimination of traffic congestion and the emissions of harmful gases to the environment. Car sharing also leads the citizens to see benefits that come from the sharing economy in their everyday living.

In this paper we presented a complete car sharing platform, Need4Car, consisted of mobile, web and dashboard / administration applications. It is agnostic of the telematics h/w installed, fully customizable, and offered as a white label product which meets the requirements of any operator who would like to set up a car sharing service. The platform contains a number of options for analysis and visualization of data to support various decisions of the business. The integration of either existing or new ones AI modules like the one described above for the characterization of the driving behavior of the users is of capital importance.

Some of the major limitation of the car sharing technology include the investment needed for the assets of the fleet, the marketing plans needed to be designed earlier so the policy of the provider to be clear from the beginning, the policy of the development of the service that will take in consideration peculiarities existed the area/country as well as the flexibility of the provider to changes either in strategic development of the sharing business, distribution of the fleet, seamless service, customer centric services.

Future steps for car sharing platforms like Need4Car are focused a) to its interconnection with data and information from other transport organizations, b) to the openness of the data maintained in its architecture to other providers, c) to inclusion of features form multimodal transportation as one-ticket for all, d) personalized suggestions for trips according to users' attributes, preferences and history.

Car sharing offers a number of benefits on urban mobility, competent enough to build the future transportation strategies: great flexibility to travel options, easy to use technology for any traveler (it does not require any technical specialization to use), it contributes to the protection of the environment, and it can be easily adopted by electric vehicles' technologies.

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