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Information Management of Demand-Responsive Mobility Service Based on Autonomous Vehicles

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Abstract

The autonomous road vehicle (AV) technology implies significant alteration of urban mobility services. The identified transit modes based on AVs are the individual cars, the demand-responsive public transportation with small or medium sized pods and the high capacity public transportation on arterial routes. The introduction of the telematics-based, shared, demand responsive mobility service requires new information management methods. Accordingly, the aim of our research was to model the structure and the operation of this rather complex information system considering both the operators and the users. Since the passenger functions are the keys of the advanced information service the conceptual plan of the mobile application with personalized functions has been also elaborated. The research questions were: how the architecture and the functions of the information system are to be modelled, what the novel information management functions of passengers and operators are, what data structure is needed and how it is related to the functions as well as what kind of functions are to be realized in the mobile application. The results are applicable as foundations for innovation and development projects aiming realization of either the back-end or the front-end components and for planning information management processes.

Keywords: autonomous vehicle, demand-responsive transportation, information management, mobile application, modelling

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1. Introduction

Nowadays focus of the mobility developments is laid on the technological and the infocommunication solutions. Emerging of autonomous road vehicles (AVs) alters the entire mobility system. Consequently, transportation modes should be more and more integrated as well as both the passenger handling functions and the operational management processes should be altered. A new, telematics-based, shared, demand-responsive transportation mode (TS-DRT) based on small or medium sized pods (AVs) turns up, which merges several currently available modes (e.g. taxi, car-sharing, ride-sharing, ride-sourcing, chauffeur service) [1–3]. The role of mobile applications is much more significant in case of this new service as this tool is the main connective medium between the passengers and the mobility service. Information acquiring, ordering, seat reservation, payment, complaining, etc. are managed via mobile application. The society barriers towards the completely new technology are diminished by the application. Therefore, one of the key elements of future autonomous passenger mobility is the development of personalized mobile applications in accordance with the back-end information system.

In this paper, we focused on the information management issues of TS-DRT. The remainder of the paper is structured as follows. States of the art is summarized in Section 2. In Section 3, the system architecture of autonomous mobility service and the aiding information system has been revealed. The functions and operational method of the system have been elaborated in Section 4. In Section 5, we have analyzed advanced information applications of current transportation modes having similarities with TS-DRT. Based on the analysis results, we have determined the concept of the mobile application for the autonomous mobility service. The paper is completed by the concluding remarks, including also potential future research directions.

2. State of the art

AVs can be employed beside TS-DRT as individual cars or for high capacity public transportation purposes on arterial routes. The individual cars are used for the most flexible travel purposes. The traditional public transportation (e.g. bus) is used in case of large volume of passengers. In this field the employment of AVs is slightly delayed. These mobility service types are to be integrated in a seamless way to realize efficient urban mobility. Two types of TS-DRTs spread: door-to-door and feeder. The new service not only takes over the role of current DRT (e.g. transporting people being disabled, or people living in less densely populated areas [4, 5]), but takes over the role of other transportation modes. Several existing autonomous small capacity pod services were introduced for demonstration purposes in a borderless EU trial project (CityMobil2). Passenger reactions to the driverless vehicle concept were positive, however, reactions at the regulatory levels were less enthusiastic [6].

Several studies collected information about opinion and expectations towards autonomous passenger services by questionnaire survey. Automation is, on average, not necessarily perceived as valuable, if the travel time and fare of the automated services are the same as those of a conventional bus. There is a relatively higher preference for autonomous service when this is implemented within a major facility (e.g. university campus) [7]. The intention of using AVs was partially explained by attitudes and contextual acceptability. The higher the driving-related sensation-seeking, the more drivers intended to use them [8]. Travelers' attitudes regarding 'sustainability of automated vehicles' is the most important attitudinal factor for using the AVs [9]. Higher-income, tech-savvy males in denser settings are more interested in autonomous services [3]. Service attributes (cost, travel and waiting time) may be critical determinants of the use of AVs. Current car-sharing users are more likely to use AVs with dynamic ride-sharing. Car drivers are more likely to choose the option shared AV without ride-sharing [10].

During our research, in order to reveal the potential expectations towards autonomous mobility services a survey was performed. However, in this study we highlighted only some relevant results regarding information management, especially mobile applications. The most important features are the fast reservation process and the provision of dynamic information (e.g. vehicle position, occupancy). Real-time information generally is one of the most required feature in case of mobile applications [11]. The personalization opportunities are also an important feature, however, providing feedback or rating the service are rather neutral. We examined the general expectations of an autonomous passenger mobility services. It can be stated that the expectation towards mobility is a fast, flexible and cost-effective service. Autonomous TS-DRT services can meet these expectations. Although, the respondents expect door-to-door services it cannot be the most effective form because of road capacity limitations.

The general impact of autonomous transportation to the traffic are examined in several papers. The major social impacts of AVs have been described: safer roads (less accidents), travel time reduction, more personalized services, improvement of energy efficiency and parking benefits [12]. Traffic dynamics becomes predictable in case of AVs. However, the transitional period with heterogeneous traffic compositions (when self-driving and human-driven cars exist together) cause complex problems to traffic modeling as precise (from autonomous cars) and stochastic (from traditional cars) traffic behaviors live side by side [13]. There are several problems to be solved before autonomous mobility services will spread widely. There are communication issues, which can reduce V2V communication efficiency (distorted or missing messages, communication device breakdown, communication with other vulnerable participants) [14]. Cooperative exchange of data between AVs boosts the attackable feature. GNSS spoofing and injection of fake messages were identified as the most dangerous attacks [15]. An attacker who is able to infiltrate virtually any electronic control unit can leverage this ability to completely circumvent a broad array of safety-critical systems [16]. In case of mixed traffic, prediction of driver's act is one of the key element. Therefore, development of prediction method for driver's propensity (physiological and psychological states) is necessary [17]. As the pods use electric energy their charging processes are also to be managed in automatic way, which has been considered during modelling.

3. System architecture

We have modeled the system architecture of autonomous demand-responsive transportation in order to reveal the components and connections between them (Fig. 1). Top-down approach was applied, where firstly the subsystems, then the elements, the connections and finally the functions have been investigated. The connections are represented by arrows; the functions are represented by capital letters on the arrows (the functions are detailed in Section 4). One letter may be marked on several arrows, if more than two components participate in one function. The system components are connected to each other and the data transmission is real-time. Therefore, telecommunication providers are the core element of the system. An autonomous demand-responsive mobility system has several external connections with other passenger transportation operators and other organizations too. The following main components have been distinguished: (1) smart passenger, (2) operational control center, (3) traffic control center, (4) autonomous road vehicle (AV), (5) smart stop and (6) maintenance (charging station/depot).

Smartphone makes the access to mobility service, provides real-time, personalized information and communication framework between passengers (1) and other system components. Passengers become 'smart' because of using smartphone. In this manner requirements towards their cognitive capabilities are reduced. The pods are operated by an operator company. The operator is responsible for planning, organizing and control of processes as well as for everyday maintenance (e.g. cleaning). In this regard, the main element for information management is the operational control center (2). As several other motorized and non-motorized vehicles run on the roads, planning, controlling and predicting of traffic should be coordinated by the traffic control center (3) which belongs to the road network operator. There is intensive cooperation (and data transmission) between control centers. On the one hand, routes of the pods are planned according to real-time and predicted traffic information. On the other hand, real-time and planned information about pods is considered during traffic control.

The autonomous vehicle (4) senses the environment via sensors, processes the input (sensed or received from other participants) data, makes driving decisions using high capacity computers and advanced artificial intelligence (AI) solutions as well as controls the vehicle movements (e.g. breaking). As there are no personnel in AVs the vehicles are equipped with several devices which are applied for passenger handling and provide information. The vehicles are connected to the control centers (V2I), to each other (V2V), to other vulnerable participants (e.g. passengers, bikers) via individual devices V2P [13] and to other facilities (e.g. smart stop, charging station – V2I).

Smart stops/stations (5) are equipped with several electronic devices which enhance the passenger mental and physical comfort (mobility-related and supplementary services). The stops and other transport networks are operated by transport network operators. During the day, the vehicle is needed to be charged several times according to the demands, therefore the charging processes are directly controlled by the operational control center (e.g. reservation charging spot), however, operation of the charging station belongs to the charging infrastructure operator. The maintenance and repair of the AVs are performed in the depots which belong to the TS-DRT operator company.
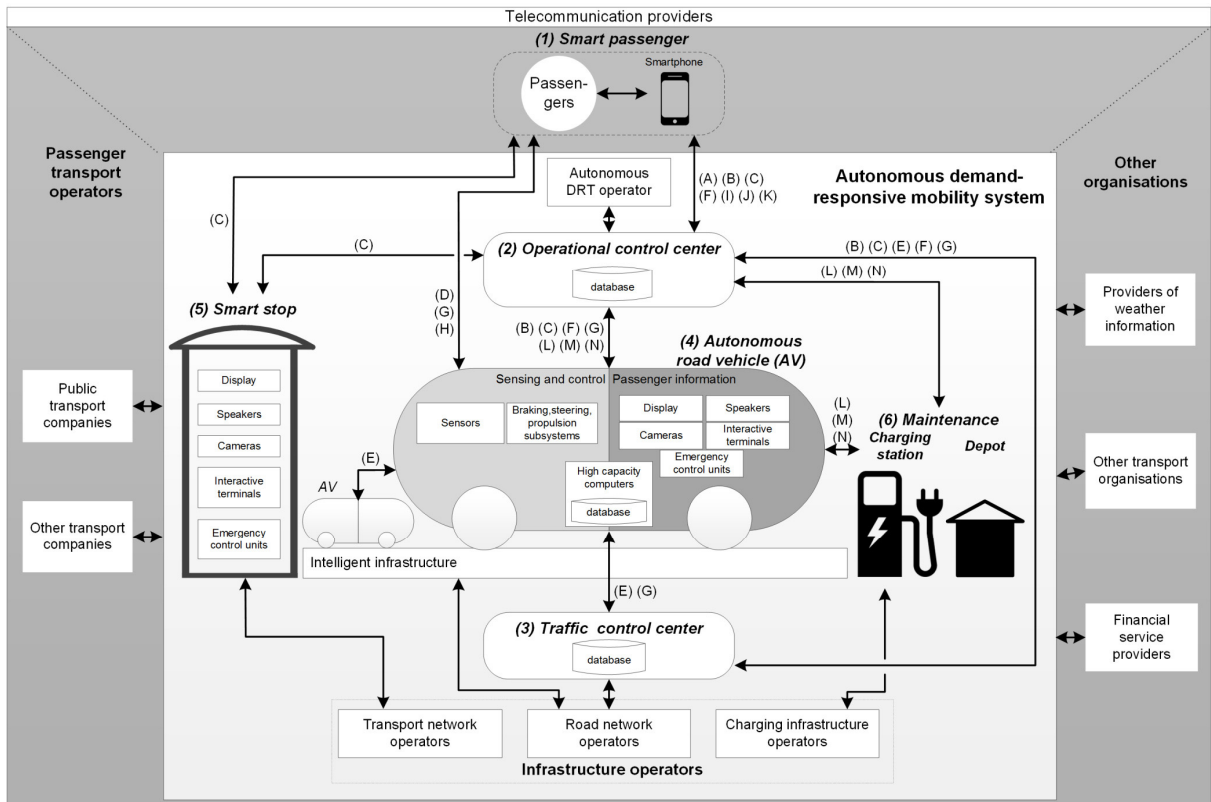
Fig. 1. System architecture of TS-DRT.

As data keep the system components together, we have elaborated the logical model of the relational database structure of the planned autonomous mobility system. Only the entities as tables are presented; without the attributes (Fig. 2). The connections between the entities are represented by arrows.
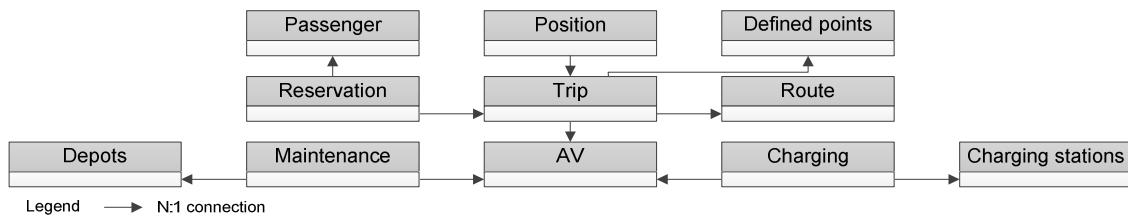

Fig. 2. Database structure of TS-DRT.

Considered type of demand-responsive services: point-to-point service without fix route or fix route service without fix stops. The mobility service is based on vehicle trips. The Route table is necessary only if several trips run on the same route defined in advance (so called fix route). Defined points table contains the origin and the destination points (e.g. smart stops). Every passenger must register in. General data of passengers are stored in Passenger table. Reservation table contains the origin and destination points, the travel time, etc. As the service is shared, several reservations may belong to one trip. Useful (carrying passengers) and empty trips are distinguished in Trip table. For controlling purposes, the position data of AVs with short time interval are collected and stored in Position table. The AV table contains static (e.g. plate number) and dynamic (e.g. charging state) data about the

vehicles. Charging processes are mapped in the Charging table, connecting charging stations and AVs. Maintenance processes are mapped in the Maintenance table, connecting depots and AVs (maintenance process is not detailed). The entire database is operated by the autonomous DRT operator having access also to the charging related data, which are managed by the charging infrastructure operators.

4. Functional model

We have revealed the functions and operational method of the main components. Our aim was to determine and describe information management processes. The autonomous DRT service differs from a regular DRT service, so we have focused especially on the differences. The functions are summarized in Fig. 3. The same numbers and letters were used for identification of the components and the functions. The functions have been assigned to the phases of the travel (before, during and after). The first step is the registration, where apart from the personal data, users can set additional options, such as selected tariff model, filter settings (e.g. vehicles suitable for wheel-chair).

Before each trip passenger sets the travel parameters (destination, number of passengers, package transport, wheelchair option, etc.). The operational control center plans the optimum route/trip considering user preferences and forecasted traffic situation, and assigns the passengers to the most appropriate available (and charged) pod. Parallel the center sends disposition to the AV. The user can track the pod on mobile application (or even at smart stop) and receives calculated arrival time and any desired push notification. The AV sends its position to the traffic and control centers, so the passengers receives these processed and value-added data.
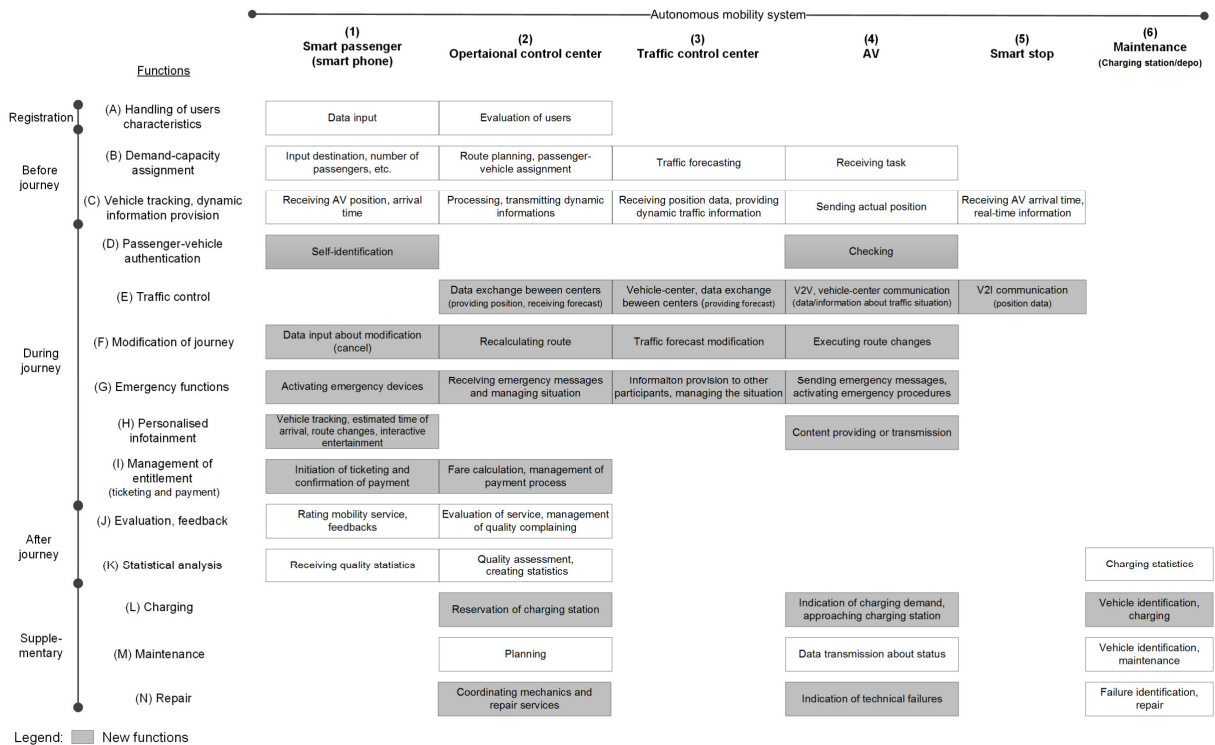

Fig. 3. Functional model.

At the selected arrival point the AV asks for authentication (e.g. generated code, mobile application, biometric identification). Without successful authentication, the doors stay closed and the order process should be checked or modified. During the travel the data are constantly exchanged between the centers and the AVs, without any human intervention. Consequently, the routes can be recalculated or the estimated arrival times updated according to the

received position and traffic data. With integration of an advanced V2V communication system, AVs can send traffic-related data to each other directly and make route changes independently. The operational control center only monitors this process having reduced information management load consequently. Since there is no driver, the route modification requests of passenger must be sent in a new way, using mobile application. The modified route is calculated in the control center, based on real-time traffic information and then forwarded to AV.

During the trip, the passengers receive personalized travel-related and real-time information on their smartphones (e.g. estimated arrival time). AV's screens may only provide collective general supplementary information. In case of emergency the in-built emergency devices can be used by the passengers or these situations are detected automatically. After processing the data and identifying the circumstances the data is instantly forwarded to the traffic authorities and rescue services. The arrival time of these participants can be significantly reduced.

Management of entitlement consists of ticketing and payment. Complex tariff structure and dynamic rates may be introduced which depends on variables (distance, current mobility demands, passenger characteristics, etc.). The payment process can be performed in all phases of the travel. In the most advanced case the bank account is debited either after the trip or at the end of the month. However, considering the current trends, payment via smartphone is rising. In case of no show passengers the operators may apply 'penalty' rates. The payment transactions require cooperation with an external financial service provider. The users can evaluate the quality of the mobility service, with feedbacks. The feedbacks are processed and stored in the operational control center to improve the service. Various statistical analyses can be created both on individual basis or on system (aggregated) level using the trip data.

The charging of an AV is initiated by sending the charging demand to the operational control center. The reservation of a charging spot is performed by control center. Therefore, intensive cooperation between the control center and the charging infrastructure operators is needed. The AV receives the coordinates of the selected charging station and navigates itself to the designated spot. The charging process requires authentication. The maintenance is strictly planned and the repairs are efficiently managed. The control center plans and coordinates these operations using the incoming status data. Intelligent diagnostic system and procedures are to be applied in the AVs, at the charging stations or at the depots. In case of breakdowns, the defective vehicle is eliminated and replaced by another one. In this case, the dispositions of the vehicles can be modified. The quick automatic re-disposition of vehicles is a real novelty in operational control, where similar aggregated service quality is provided with less vehicle as a result of dynamic assignment of demands and capacities. In this case the aspects of human resources can be disregarded.

The most relevant functions of the operational control center are handling user data and travel parameters, provision of personalized information, planning, organizing, control of processes (e.g. coordination of demands and capacities, timing of maintenance, booking of charging point), sending dispositions, calculating routes (based on information from the traffic control center), fare calculation, management of payment process, evaluation of service and quality assessment. The most relevant functions of the traffic control center are control and prediction of traffic parameters; provision of real-time traffic information; data exchange with road network operators; and statistical analysis of traffic parameters supplying data for decision-making.

5. Concept of integrated information (mobile) application

A multifunctional passenger information service is a precondition for TS-DRT. As human components are replaced by machines the role of infocommunication technology is more important because every communication is realized by machines. The platform to access the mobility service is the smart phone application.

As TS-DRT is a mix of several current high developed IT based mobility services, we have analyzed the mobile applications of the most relevant, similar modes. The concept of the information application has been elaborated according to the situation analysis, the results of the questionnaire survey and our own experiences.

5.1. Situation analysis

We have selected applications representing the following modes: taxi (Főtaxi – taxi company in Budapest), ride-sharing (BlaBlaCar) and ride-sourcing (Uber). These transportation modes show the strongest relationship with TS-DRT. The most relevant aspects of the analysis have been determined following a systematic approach. After general features the functions have been analyzed before, during and after travel (Appendix A. – the last column

contains the suggested features of the mobile application of TS-DRT; see in details in 5.2). The detailed technical description of operational characteristics of the applications was not available. Accordingly, the analysis has been performed by us from user perspective. During the analysis, we have tested the mobile and web applications and ordered vehicles to obtain empirical information about operational processes. The mobile application of Főtaxi is user-friendly with several advanced functions. The main advantages are the fare calculation and the detailed description of the cabs (e.g. picture). Application of Uber is rather user-friendly, innovative solution is the dynamic ride-sharing service supplemented with walking navigation, which facilitates the vehicle findings. BlaBlaCar service relies on a well-built mobile platform, which helps users to find the best match to carry out a money-saving and efficient way of travel.

5.2. Concept

Following the previous aspects, we have elaborated the concept of the TS-DRT mobile application. On the one hand, the advantageous exemplary properties of the analyzed applications have been built-in. On the other hand, novel functions have been added in accordance with the autonomous nature of the mobility service. The exemplary and the novel functions have been summarized in the last column of Appendix A.

Data can be entered and queried using voice commands. This feature makes the service more attractive and easier to use, especially for blind people (1.7. Voice commands). Frequently-used destinations (routes) are monitored by the system and the application offers these destinations to the users automatically as a result of self-learning capability (4.4. Adding regular travel options). In case of pre-booked travels, the date and time of travel is exported to a calendar. The calendar warns the passengers before the travel. Hereby the number of forgotten trips can be reduced (4.5. Calendar notification). The personalized setting options during ordering are improved; e.g. wheelchair option can be selected (4.6. Order parameters). In case of multimodal travels, a common platform is provided via the application for payment. In this manner, combined tariff systems and advanced payment methods can be applied (5.11. Combined payment). After the trip the amount of saved energy (reduced environmental impacts) compared to the private car usage is displayed. In this way, the autonomous mobility services can be promoted too (6.6. Display of saved energy).

We have determined several novel functions required due to autonomous service. All modifications (destination, new waypoints, cancel, etc.) should be performed using the application. The modification options should be regulated avoiding large turnouts (5.3. Modification of travel via application). As human interaction is impossible anymore because of absence of human driver the easiest and fastest way for payment is the automatic procedure (possibly after confirmation via mobile application). The location data and the associated timestamps are used in case of sophisticated and dynamic rate calculation (5.9. Automatic payment). The entire service (not only the human driver) can be evaluated via the application (6.2. Service rating possibility).

6. Conclusions

Demand-responsive mobility service based on AVs is still not realized for everyday use. Therefore, our results have high relevance for further research, innovation and development. The main contributions are the model of information system architecture (including data model), the functional model describing the information management activities of the system components, the method for evaluating and comparing the capabilities of exemplary applications used for similar purposes and the model of the 'ideal', integrated information application. The introduced models are appropriate for comprehensive logical preparation of the realization. The subsequent steps on physical level can be derived from the results using further advanced analysis and modelling methods [18, 19]. We have found that applying the proposed information system with real-time data facilitates the precise and efficient coordination of travel demands and vehicle capacities. The proposed personalized and self-learning information services improve the perceived quality. We faced as lesson learnt that several aspects in their context are to be considered during analysis of applications. TS-DRT is to be integrated with other transportation modes, where the 'tool' of integration is the advanced information management. Entire travel chains can be realized in this way. Our further research focuses on elaboration of advanced

planning and IT-based operational methods of TS-DRT (with special regards to demand-capacity coordination) as well as on assessment methods regarding impacts of TS-DRT.

Acknowledgements

Appendix A. Table. Analysis of existing mobile applications and concept of TS-DRT mobile application

	Functions	Főtaxi	BlaBlaCar	Uber	*TS-DRT*
	1	2	3	4	5
1. General	1.1. Ordering (web/mobile app)	✓✓	✓✓	✓✓	✓✓
	1.2. Language options	HU/EN/GE	local language	local language	**local language**
	1.3. Availability	Budapest	international	global	**global**
	1.4. Operating system compatibility (Android/IOS/Windows)	✓✓✓	✓✓✗	✓✓✓	✓✓✓
	1.5. Customization	✓	✓	✓	✓
	1.6. Feedback options	✓	✓	✓	✓
	1.7. Voice commands	✗	✗	✗	✓
	1.8. Help	✓	✓	✓	✓
2. Visual display	2.1. Navigation among the functions	✓	✓	✓	✓
	2.2. Advanced map interface	✓	✗	✓	✓
	2.3. Displays vehicles on map	✓	✗	✓	✓
	2.4. Photo of vehicle	✓	✓	✗	✓
3. Textual display	3.1. Vehicle information (car brand, type, plate no.)	✓✓✓	✓✓	✓	✓✓✓
	3.2. Dynamic information (arrival time, fee, free places)	✓✓✗	✗✗✓	✓✓✗	✓✓✓
	3.3. Additional information (driver rating, accuracy, package transport, animal transport, smoking, vehicle rating, cleanliness)	✓✗✗✗✗✗	✓✓✓✓✓✗✗	✓✗✗✗✗✗	✗✗✓✗✗✓✓
4. Before travel	4.1. Enter starting point (GPS, text, map)	✓✓✓	✓✓✗	✓✓✓	✓✓✓
	4.2. Enter arrival point (text, map)	✓	✓✓	✓	✓✓
	4.3. Departure time adjustability	✓	✓	✓	✓
	4.4. Adding regular travel options	✗	✗	✗	✓
	4.5. Calendar notification	✗	✗	✗	✓
	4.6. Order parameters (air-condition, animal transport, package transport, passengers no., wheelchair)	✓✓✗✗✗	✓✓✓✓✗	✗	✓✓✓✓✓
	4.7. Optional vehicle category	✓	✗	✓	✓
	4.8. Ride-sharing mode	✗	✓	✓	✓
	4.9. Navigation to starting point (in ride-sharing mode)	✗	✗	✓	✓
	4.10. Tracking of arriving vehicle	✓	✗	✓	✓
	4.11. Notification about arrival (message, voice signal)	✓✗	✗✗	✓✗	✓✓
	4.12. Order cancellation in the app	✓	✓	✓	✓
5. During travel	5.1. Sending destination automatically	✗	✓	✓	✓
	5.2. Displays vehicle on map	✓	✗	✓	✓
	5.3. Modification of travel via application	✗	✗	✗	✓
	5.4. Sharing arrival time	✗	✗	✓	✓
	5.5. Calculation of fares (base fee, km/min fee, cancellation fee)	✓✓✗	✓✗✗	✓✓✓	✓✓✓
	5.6. Discounts	✗	✗	✓	✓

End of Table

	1	2	3	4	5
	5.6. Application of variable fees	✗	✗	✓	✓
	5.7. Payment options (cash, credit card, taxi card, via app)	✓✓✓✓	✓✗✗✗	✗✗✗✓	✗✗✗✓
	5.9. Automatic payment	✗	✗	✗	✓
	5.10. Built-in fare calculator	✓	✗	✗	✗
	5.11. Combined payment (with public transport)	✗	✗	✗	✓
6. After travel	6.1. Save travel information	✓	✓	✓	✓
	6.2. Service rating possibility	✗	✗	✗	✓
	6.3. Driver rating possibility	✓	✓	✓	✗
	6.4. Vehicle rating possibility	✗	✗	✗	✓
	6.5. Passenger rating possibility	✗	✓	✓	✗
	6.6. Display of saved energy	✗	✗	✗	✓

Legend: existing or developed exemplary functions, novel functions   Results based on data of 2016 winter

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