On the Integration of Shared Autonomous Mobility on Demand in Mobility Service Platforms

Felix Schwinger[1,3], Ralf Philipsen[2], Simon Himmel[2], Matthias Jarke[1,3] and Martina Ziefle[2]
[1]*Information Systems, RWTH Aachen University, Aachen, Germany*
[2]*Human-Computer Interaction Center (HCIC), RWTH Aachen University, Aachen, Germany*
[3]*Fraunhofer Institute for Applied Information Technology FIT, Sankt Augustin, Germany*

Keywords: Mobility Service Platform, Ride-sharing, Mobility-as-a-Service, Web Services, Platform Architecture.

Abstract: Recently, travelers increasingly book trips that combine public transportation with emerging mobility modes such as ride-sharing. Mobility service platforms aim to integrate this heterogeneous mobility mix on a single software platform. In practice, only first appearances of collaborations between public transit companies and ride-sharing companies have emerged so far. Especially with the coming emergence of autonomous vehicles, ride-sharing services will become a vital mobility mode as part of Mobility-as-a-Service schemes. Therefore, this study aims to research the requirements for integrating ride-sharing services into a mobility service platform from a user-centered and technical perspective. For this, we first analyzed the overall attitude towards autonomous ride-sharing in a citizen workshop and evaluated a prototype of the system in a small user study. Additionally, we conceptually integrated the service into an existing reference platform for mobility services and investigated the technical and operational differences between public transportation and ride-sharing services. The analysis shows that autonomous ride-sharing services are integrable into a mobility service platform but have distinct requirements that other mobility services such as scooter-sharing or public transit do not have.

1 INTRODUCTION

Due to an ongoing digitalization, the number of different transportation modes in urban mobility systems has significantly risen in recent years (Shaheen and Cohen, 2019). Next to private and public transit, modern urban transportation systems increasingly consist of a range of smartphone-enabled mobility services such as car-, bike-, scooter-, and ride-sharing. Road networks are at their limit in urban areas, congestion is the norm, and parked vehicles consume valuable space in cities. These emergent modes may help promote a switch from private transportation to more environmentally and space sustainable mobility modes. In particular, the heterogeneity of the travel modes offers the opportunity to personalize the mobility service perfectly to the travelers' requirements matching the flexibility of private transportation. However, it also risks burdening travelers with too many travel options.

To allow travelers to handle these complex multimodal transportation networks, mobility service platforms (MSPs) aim to integrate different travel modes into a single platform (Jittrapirom et al., 2017). These platforms implement the idea of Mobility-as-a-Service (MaaS) and mobility-on-demand (MoD), where mobility is not enabled by owning a private vehicle but by subscribing to a service. Multiple MSPs are differentiated depending on the degree of integration and their underlying cooperation scenarios (Beutel et al., 2018b). The least integrated platform only allows viewing travel information, while the most integrated platform offers the booking of intermodal trips that combine products of several mobility providers. Overall, MSPs ease the problem of manually comparing and combining mobility offers for the customer; the tighter the integration on the platform, the easier the service is usable for the customer.

Among other transportation modes, ride-sharing is a rapidly rising mobility mode (Wenzel et al., 2019). Ride-sharing is provided by so-called transportation networking companies (TNCs) and describes primarily door-to-door trips by taking a just-in-time called vehicle (Rayle et al., 2016). In contrast to regular taxis, this mobility form offers the possibility of pooling customers with similar destinations in one vehicle, thus reducing the required vehicles. Furthermore, autonomous vehicles will become available in the following years. As autonomous vehicles will be expensive,

Schwinger, F., Philipsen, R., Himmel, S., Jarke, M. and Ziefle, M.
On the Integration of Shared Autonomous Mobility on Demand in Mobility Service Platforms.
DOI: 10.5220/0010675000003058
In *Proceedings of the 17th International Conference on Web Information Systems and Technologies (WEBIST 2021)*, pages 332-340
ISBN: 978-989-758-536-4; ISSN: 2184-3252

their usage will be concentrated on TNCs offering autonomous mobility-on-demand (AMoD) services before becoming more publicly available. Hence, autonomous vehicles are of particular interest to TNCs (Pakusch et al., 2018). Ride-sharing is already one of the fastest-rising mobility modes. In conjunction with autonomous vehicles in shared autonomous mobility-on-demand (SAMoD) services, the popularity may even further rise.

While an MSP ensures that technically travelers can use all mobility modes in conjunction, it does not influence whether the mobility services on it are competing or complementing each other and how the user is considered in this approach. Shared scooters are more suited for short trips and primarily displace bike, car, or foot trips (Hollingsworth et al., 2019). Services for short trips are often seen as complementing public transportation, as their on-demand character makes them especially suited for first-mile-last-mile trips (Cohen and Kietzmann, 2014). In contrast, ride-sharing currently most prominently replaces taxis, public transport, and private car legs (Tirachini, 2019). Herein also lies the chance and risk of ride-sharing regarding environmental, equity-related, and traffic-related challenges: ride-sharing can compete or complement public transportation services (Shaheen et al., 2020).

To understand why and when new mobility services compete with established transportation modes, it is crucial to understand the individual users' mobility behavior, needs, and constraints. Research shows that especially flexibility given by owning a car (Philipsen et al., 2020) is a key barrier for using public transport - and this flexibility is evaluated differently for varying users. In addition to understanding the user, it is crucial to integrate the user iterative into the whole development circle, from scratch (Svanaes and Seland, 2004) via video-based scenarios (Flohr et al., 2020) to prototypes of multimodal travel systems (Himmel et al., 2016). However, when autonomous vehicles join the game, it is even more critical to understand user acceptance (Jing et al., 2020): the overall chances of autonomous driving are high, but users' constraints have to be addressed. In addition to the complexity of SAMoD from the autonomous vehicle's point of view, it is also challenging to understand which new requirements MSPs have to fulfill when integrating these services.

SAMoD has a pivotal role in the future of transportation systems. It promises to match the flexibility of private ownership-based transportation with the accessibility of public transportation. Its highest potential is reached if the service complements public transportation on routes with lower demand, as public transportation offers higher throughput routes with high demand. Recent studies suggest that SAMoD may compete with public transportation systems without regulation and the right incentives instead of complementing them (Liu et al., 2017). However, most of these studies focus on economic, societal, environmental, political, or governance aspects of the problem but rarely focus on the user or technical challenges regarding the integration into an mobility service platform (MSP) (Pakusch et al., 2018). This paper researches the opportunities and technical difficulties of integrating SAMoD into an MSP that interconnects multiple available transportation modes in intermodal journey chains. For this, we will introduce a developed prototype for autonomous ride-sharing services consisting of web services and a corresponding mobile application and conceptionally integrate it in an MSP. We consider three relevant perspectives: the user's, the mobility provider's, and the MSP operator's perspective while focusing on the user and technical requirements. In this position paper, we propose first solutions; hence the evaluation is still limited.

2 APPROACH

We identified several open questions in the literature concerning the integration of (autonomous) ride-sharing: 1) research of user requirements integrating of shared autonomous mobility-on-demand (SAMoD) services into mobility service platforms (MSPs), 2) the requirements of SAMoD providers toward a MSP, 3) the novel requirements of a MSP operator regarding the SAMoD provider integration. In the following, we introduce the scenario of an MSP and a pre-existing reference platform. Next, we describe our methodology for tackling the identified research gaps.

2.1 Scenario

As the envisioned scenario for a multimodal MSP and Mobility-as-a-Service (MaaS) is, if any, only implemented in local projects, we will introduce it here. We base our work on the mobility service platform on the reference platform architecture for mobility as defined by the Association of German Transport Companies in its normative model VDV-436[1]. An MSP integrates multiple mobility products from different providers into one single platform. Figure 1 shows the mobility service chain on an MSP, from login, to information gathering, booking, travel, and finally, customer assistance during the trip. Concurrently to other phases,

---

[1] https://www.beka-verlag.info/advanced_search_result.php?keywords=vdv+436 (only available in German)

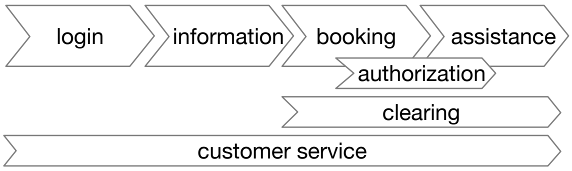

Figure 1: Sketch of a holistic mobility chain over all phases.

the phases of authorization, clearing, and customer service may occur. In the login phase, the customers identify themselves towards the platform. Next, customers may request information about itineraries and book them in the next step. Depending on the level of integration, these itineraries may already consist of offers from multiple transportation companies. Finally, the customer may receive further assistance regarding the trip, for example, turn-by-turn directions. The authorization phase handles the issuing access privileges to the traveler, and clearing describes the phase where the customer is billed with the actual cost of traveling. Additionally, an MSP offers customer service along with all steps of this holistic mobility service chain.

As VDV-436 represents a reference architecture, it aims to capture all possible characteristics of possible specific technical implementation of platform architectures for mobility. We, therefore, assume that the technical concepts are easily adaptable to different implementations of MSPs in other regions and do not depend on the actual implementation of the MSP. A possible technical platform is shown in a condensed form in Figure 2. The behavior of all presented components is defined, guaranteeing the replaceability of components. For a complete overview, we refer the reader to Beutel et al., 2018b. The architecture consists of three main functional groups: *information*, *platform management*, and *booking*. The information group integrates travel information and products. Its router can chain different mobility modes into intermodal travel chains by using linked data concepts on the external data sources. The platform management group deals with internal platform tasks, e. g., user management and user preferences. Finally, the booking and account group handles the booking of products on the distinct external subsystems in a transaction-safe manner. External mobility providers can join the platform by providing data to the information group and adapting their booking system to receive booking requests from the platform. For the integration of ride-sharing, we will focus on these two external systems.

2.2 Methodology

For the first research gap related to the users' requirements of the integration of SAMoD into MSP, we first analyzed the overall attitudes towards such a system in citizen workshops, went deeper using online focus groups (due to COVID-19, no more public workshops were possible) and evaluated the prototype of a SAMoD service in a small user study in a real-life scenario in the town of Aachen. The empirical approach was based on a consecutive mix of qualitative and quantitative methods to identify and quantify user needs and attitudes. The qualitative procedure was guideline-based, and the resulting discussion and interview transcripts were structured and evaluated using content analysis. The quantification was mainly done with conventional questionnaires, based on, among others, agreement scales and semantic differentials to capture user perceptions. For addressing the requirements a SAMoD service imposes on an MSP (Gap 2), we checked the organizational and technical requirements of a developed prototypical SAMoD service against the previously introduced reference architecture. For this, we will introduce the system architecture of a

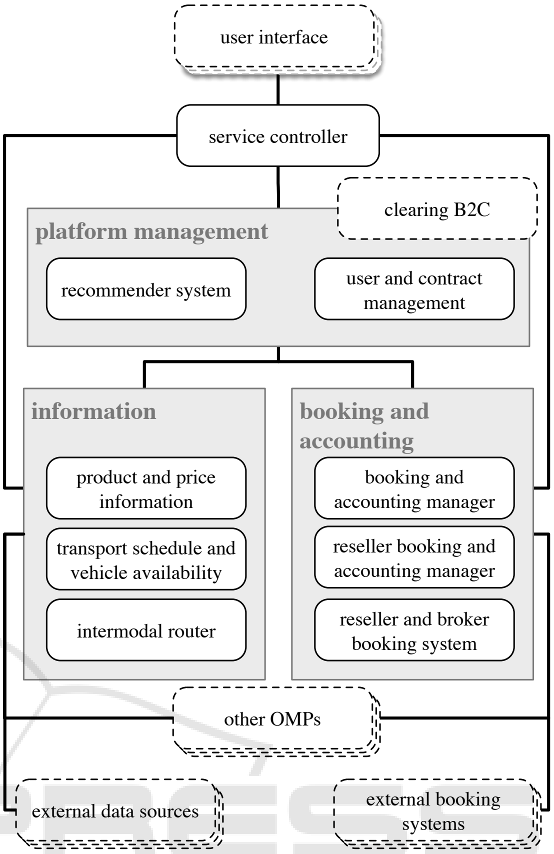

Figure 2: Architecture of an open mobility standard as defined by *VDV-436*, adapted and truncated from Beutel et al. 2018b. Solid boxes define internal platform components, dashed boxes represent external components, layered dashed boxes indicate that more than one such component may exist.

prototype we have developed and analyze how it could be integrated into an MSP, and gather possible requirements. As currently, no implementation of an MSP exists, this integration has to be performed conceptionally. Finally, for Gap 3, regarding the needs of an MSP towards integrated SAMoD services, we align the requirements of the reference mobility service platform with that of SAMoD providers. As of now, existing architectures have not considered the mobility mode offered by autonomous ride-sharing. Therefore, we analyze which additional requirements arise to integrate ride-sharing services with other transportation modes.

3 RESULTS AND DISCUSSION

In the following, we introduce the system architecture for a shared autonomous mobility-on-demand (SAMoD) service that we developed as part of a German research project[2]. We and the project consortium developed business models, process diagrams, and software prototypes for autonomous ride-sharing services. This service acts as a prototypical mobility provider for the conceptual integration into an MSP in this paper. This integration considers the mobility providers', the platform operator's, and the customers' requirements. Our contributions to the problem are as follows: We propose a prototypical architecture for ride-sharing services and present selected requirements for such a software system. Both a frontend application and a corresponding backend have been implemented and evaluated with users in user tests. Based on this prototypical application, we checked the requirements against a previously designed MSP. The MSP and the SAMoD platform have been developed in a user-centered design approach, allowing easy comparability between the requirements. The architecture of the MSP has not influenced the proposed SAMoD platform, as different people were involved, and we were interested in the differences between a special-purpose system for ride-sharing and a general-purpose MSP. To align the requirements, we check which information needs to be exchanged between the MSP and SAMoD. We manually align this information flow with the requirements of the platform operator and the mobility service provider to retrieve the final requirements.

3.1 Platform for Mobility on Demand

We selected a user-centered design approach for the ride-sharing service system's architecture that places the user in the center during the whole development cycle: We first defined the user scenarios of the mobility service, from which we then derived corresponding use-cases. The initial user requirements could directly be derived from the use-cases. For the technical requirements, we analyzed existing external systems and external policies. Using the requirements, we listed distinct tasks that the system is required to perform. After grouping these tasks according to their topic to components, we obtained the first prototypical system architecture. We then created corresponding activity diagrams by analyzing how the platform implements the use-cases. With these activity diagrams, we could then analyze the information flow between the components for specific use-cases. Finally, we derived the data and interaction models from the information flow, resulting in a complete system architecture description.

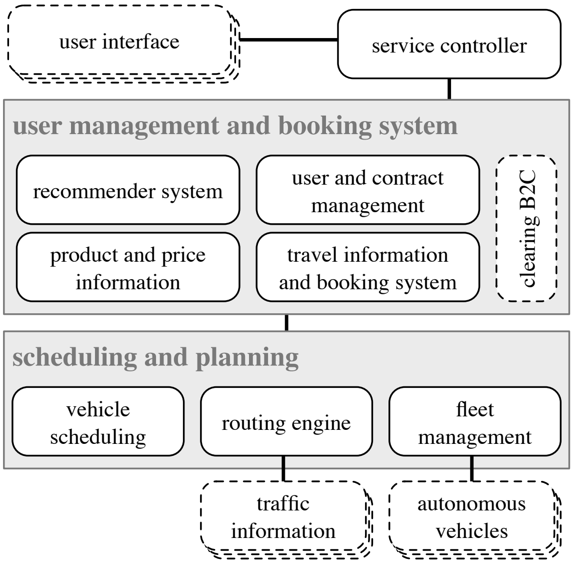

Figure 3: Prototype system architecture for ride-sharing services. Solid boxes define platform components, dashed boxes represent external components, whereas layered boxes indicate that more than one such component may exist.

Following this design methodology, we developed the system architecture (see Figure 3). For the platform's primary task of offering on-demand mobility offers, important data messages were defined: travel request, travel offer, travel order, and travel confirmation. The communication between user and system is initiated in the user interface, which communicates with the user management and booking system over a service controller. Inside the booking system, the main components are the product and price information system, storing information about purchasable products such as monthly tickets and their prices. It is also able to annotate journeys computed by the scheduling system with a price. The task of the travel information and

---

[2] https://www.autonomousshuttle.de/en/

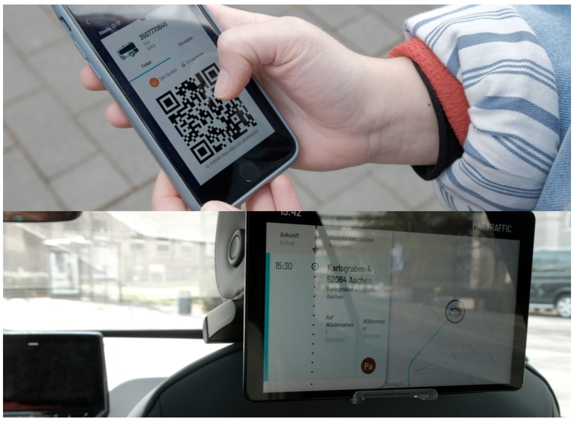

Figure 4: User interfaces of the developed system during user testing. Top: Smartphone application managing the trip with displayed QR code for check-in at boarding. Bottom: Invehicle display for visualization of current trip progress.

booking system is the provision of travel information and processing all information regarding the booking process, i. e. handling the booking, rebooking, or cancellation of trips. Suppose a user inquires travel information using a travel request, this request is forwarded by the service controller to the booking system. The booking systems may optionally annotate this request with the user's preferences using the recommender system and sends this request to the scheduling and planning component. This travel request includes a pick-up and drop-off location and either a departure or arrival time. Next, the planning component checks whether the user's travel request is satisfiable by one of the autonomous vehicles with a dial-a-ride algorithm (Gökay et al., 2019). This scheduling component can always access the current position of the vehicles and has a real-time traffic forecast for its routing engine. If a valid schedule for the request is found, the scheduling component generates multiple offers for the customer. This offer is then sent back to the user through the booking system. Before reaching the user, the offer, including a specific itinerary with pick-up and drop-off locations and time windows, is annotated with a particular price by the price information subsystem in the booking system. If the user chooses one of these offers, the user interface sends an order, which gets relayed to the scheduling subsystem. The order's validity is checked as other bookings may have already changed the vehicles' schedules. If the order is valid, it will get persisted in the vehicle's scheduling, and the fleet management informs the corresponding vehicle of its new schedule. Finally, either a positive or negative confirmation is generated, which is sent to the user. All data types and the interaction protocol were modeled using the OpenAPI specification language and implemented for this work.

An initial test of the implementation of the entire system in real traffic (Figure 4) with $N = 10$ users (laypersons and usability experts) and non-autonomous vehicles indicated that the implementation concept works for different scenarios (e. g., single trip, ride-sharing, trip cancellation, competing vehicles, etc.) and was positively perceived by the users. The mobility service itself and the interaction with the service were rated as useful, reasonable and offering added value, which resulted in a general willingness to use the system. In addition to these classic usability aspects, a positive - in the sense of a pleasant, enjoyable, and activating - semantic perception of the mobility service was found regarding the user experience. However, it also became apparent that flawless communication and interaction with the vehicle in an autonomous system are essential. Numerous challenges arise from the user's point of view alongside the mobility chain, which are explored in more detail in the next chapter.

3.2 Integration of Mobility on Demand

To the best of our knowledge, shared autonomous mobility-on-demand (SAMoD) has not been technically and holistically integrated into a mobility service platform (MSP). Therefore, we combine these two concepts by comparing the concept of an MSP as defined by VDV-436 with the requirements elicited during the development of the previously introduced prototypical SAMoD service. We evaluate the integration challenges along with all phases of the mobility service chain (Figure 1). While sharing modes such as car-, bike-, scooter-sharing have been regarded during the development of the reference platform, ride-sharing and autonomous ride-sharing have not. Therefore, we analyze which new requirements stem from the concept of on-demand ride-sharing and which from the integration of autonomous vehicles.

3.2.1 Novel Concepts

For the following requirements analysis, we define and explore the concept of a vehicle's *autonomy* and the concept of *ride-sharing*.

Autonomy. We regarded the levels of automation as defined in SAE J3016[3]. The norm differentiates between six levels of automation, with Level 0 describing no automation and Level 5 representing full automation. In Level 0 all tasks are performed by the driver, whereas in Level 5 the passengers of the vehicle do not necessarily have to perform any task. For analyzing the information flow and the backend's requirements

---

[3] https://www.sae.org/standards/content/j3016_202104/

for autonomous vehicles, we classified these levels into two parts: Level 0-3, where a human driver must be available in the vehicle and Level 4-5 where the driver becomes optional. Regarding autonomous driving from the platform's perspective, no further division is necessary. For example, only the distribution of driving tasks between driver and vehicle differs between Level 0 and Level 3. Only starting with Level 4, real autonomous vehicles have to be regarded, especially because a driver can not necessarily support passengers with their questions. This means that for such a system, the autonomous vehicle must understand the driving assignments and that users can also perform all tasks without a driver being present. On the upside, autonomous vehicles may react more quickly to updated itinerary schedules than a human driver could.

Ride-sharing. The most prominent characteristic of ride-sharing or MoD is that the vehicles are only operating *on-demand* and that travelers can share the rides. A user can request a pickup and drop-off location, a time, and optionally a time-frame for traveling, resulting in a high flexibility. The system then dynamically computes the routes. Often only time windows and rough places are communicated toward the customer at first. As the departure window gets closer, the system concretizes this time. This approach allows the system to optimize its itineraries later on and to fit in further mobility requests on the schedule of a vehicle (Gökay et al., 2019). The vehicles do not follow a transparent schedule for the user; therefore, traveling without booking a journey is impossible. Due to this dynamic, it is also challenging for passengers to identify their assigned vehicle at the pickup location - especially for fleets of identical colors with a low model variance - and their stop at their drop-off location. If such vehicles gather in one location, e. g., a city's main station, it will become cumbersome to identify a single vehicle in a fleet of vehicles. The ride-sharing service on the other side also needs to identify distinct passengers to know when the journey may be continued. In a non-autonomous vehicle, the driver may check the identity of each customer; in an autonomous vehicle, this process needs to be automated, possibly by relying on the smartphone applications of the passengers.

3.2.2 Identified Requirements

Following the service chain, as defined in Figure 1, the following differences have been identified compared to traditional transportation modes in the different phases of an MSP due to the novel concept of ride-sharing or the autonomy of the vehicles. We regard differences in the MSP and the proposed ride-sharing system.

Registration and Login. During the initial registration at the MSP, there is a greater need for verifying the user, as users may be alone on the autonomous vehicle. This verification may happen in person, via online video, or based on other verification media such as IDs or credit cards. Similar checks are sometimes already performed by car- or bike-sharing providers. These mobility modes have in common that the traveler uses the vehicle alone, without the mobility provider's supervision. This verification should happen once per mobility platform, so the needs between different mobility providers should be aligned. As this check is only performed on the mobility platform, this information needs to be shared between MSP and SAMoD provider.

Information Provision. Most MSPs support two ways of obtaining travel information. One way is the *timetable or availability* functionality. Here, a user selects a specific location and is interested in either the departures of scheduled vehicles near there or in the availability of shared vehicles in the vicinity. This information is not useful for ride-sharing, as vehicles only adjust their schedule only on-demand after booking a trip. The only sensible method for inquiring travel information about ride-sharing vehicles is the journey planner, which plans a particular trip and augments the schedule of a vehicle. The MSP can also only integrate ride-sharing if both origin and destination are known in the query. Additionally, the platform may also offer fixed products for ride-sharing, e. g., products like a monthly pass that are not linked to a specific trip. However, the description of these fixed products is identical to other already described products, such as a monthly ticket, not bound to specific itineraries.

One key concept of the reference architecture for mobility platforms is that the MSP is able to provide all information from its local data aggregator. The data aggregator operates on semantically linked data for the integration of different mobility modes and products. Suppose a user, for example, inquires about currently available shared bicycles or the timetable for a specific bus stop. In that case, the platform is able to provide this information without requesting it from the mobility operator. Therefore, the mobility providers must always provide the necessary information to the MSP as an external data supplier. The platform itself then handles the further steps of computing integrated mobility itineraries. For MoD services (even non-autonomous), this approach is unsuitable: for strategic reasons the service provider will neither share the position and state of its vehicle fleet in real-time as crucial trade secrets can be extracted for it, nor will it share its route planning algorithm with a third-party, as this would be required to compute valid ride-sharing trips. Therefore, such information will not be shared with an MSP. Currently, the MSP only provides information on actually booking rides in its trip planner, meaning that it can also not estimate which trips the SAMoD provider can fulfill. Proposed standards for standardized ride-sharing application programming interfaces (APIs), such as GTFS-flex[4], only allow general information about the booking of ride-sharing services, such as a geofence and time windows in which booking rides is possible. These APIs, however, lack information on a trip level. This means that ride-sharing services break the key concept of data locality and that mobility platforms are required to integrate an external booking system directly into the routing phase. However, suppose a mobility provider is directly integrated into the routing process. In that case, it needs to reply to many travel requests, some of which are directly discarded and never shown to customers. This becomes apparent when regarding the integration of public transit and ride-sharing: The algorithm has to find out where to best end a public transit leg and begin the ride-sharing leg.

Booking. While the booking process of intermodal mobility itineraries itself remains the same, specific characteristics of on-demand ride-sharing have to be considered. One key aspect here is the on-demand character of ride-sharing services, which means that each mobility request is answered with an individualized trip. There is a limit on how long the mobility provider can guarantee the validity of offered trips. The booking of other passengers may also influence the schedule so that a specific offering is no longer valid. Partial solutions to this problem include that the customer does not receive a specific departure time and location but rather a location and time window that will get updated in real-time once the departure time is getting nearer. Locking offers to a customer to ensure that an offer is bookable for a specific duration is infeasible in practice: many travel requests on a mobility platform are performed for informational purposes without booking a particular trip. Especially with the aforementioned aspect of being directly integrated into the routing process, this becomes challenging. This means that even under regular operation, the booking of ride-sharing trips may fail as the mobility provider cannot fulfill the initially promised route as the customer waited too long between the inquiry of the journey and the actual booking.

As ride-sharing bookings will fail more often than the booking of regular public transit tickets, the MSP must ensure that the booking of intermodal trips is made in a transactional way. If a customer books a trip spanning over multiple service providers, the platform has to communicate with each of these service providers for the actual booking of the individual trips. It must never happen that the customer of the MSP receives and is billed for part of the tickets of a complete travel chain, as parts of the bookings failed. These internal booking steps may fail; for example, a user books a trip, including a ride-sharing and train leg. When booking, the ride-sharing operator cannot fulfill the initially proposed route anymore because the proposed vehicle has reached its capacity limit in the allotted time slot as another passenger booked a trip. Now the customer should not receive the also included train ticket of the journey, but rather the whole booking of the travel chain must be rolled back. Therefore, the systems of the mobility service providers must provide either a way to cancel bookings for a specific time after the initial booking or must implement locking mechanisms that ensure that either all mobility services are booked or none.

Once an itinerary including ride-sharing legs is booked, the ride-sharing provider needs to be informed about the booked route in order to persist it into its fleet management. Furthermore, the ride-sharing provider must be informed about potential delays on previous legs for seamless integration. For smaller time deviations, the provider may be able to adapt the schedule to real-time data, compensating for possible delays.

Travel Assistance. In the travel assistance phase, the system assists the customer with various tasks regarding their mobility. These tasks include finding the correct departure location, communicating potential delays to the traveler, helping the traveler identify the proper vehicle to board, or helping the customer in case of disturbances to the itinerary. This vehicle identification is more complex for ride-sharing vehicles, as the trips and the identification means are more dynamic. Especially for regions with many departures or arrivals, this will be a challenge. Safely identifying the correct vehicles may technically be done with the help of QR-codes the travelers are required to scan when entering the vehicle, but identifying the right vehicle from far away remains challenging. The system may send identifiers, such as a vehicle number or a vehicle name and the exact current vehicle position for visualization to the traveler beforehand. Once the traveler is on board, she must also exit the vehicle at a specific stop again. or this, the system might show specific stop information inside the vehicle with the help of pictographs and send it to the user's mobile application. In case of delays along a booked multimodal journey,

---

[4] https://github.com/MobilityData/gtfs-flex

the MSP may propose alternatives to the customer, e. g., the ride-sharing leg may be postponed when a prior leg is delayed.

Authorization. During the authorization phase, passengers receive their tickets. Depending on the actual implementation of the autonomous mobility service, the system may be open or closed. In a closed system, people cannot enter the vehicle without valid authorization, e. g., the doors of the vehicles do not open without a valid ticket. In an open system, everyone is free to enter the vehicles, as there is no physical barrier hindering people from doing so. For autonomous ride-sharing, closed systems will likely emerge, as the system needs to know when all passengers have boarded to continue the journey.

From the user's point of view, ride-sharing providers must take the perception of safety into account. In addition to general vehicle safety, the influence of other passengers comes into play here. It became apparent that users are concerned that other passengers could impair the vehicle's cleanliness and safety, as well as the safety of any goods to be transported, without the control provided by the human driver in a conventional vehicle. Interviews revealed that users - especially for specific private trip purposes - prefer a closed system where they can influence boarding. Alternatively, cameras and microphones for security purposes would be acceptable from the user's point of view, while for pure interaction between user and vehicle, this is not wanted (Biermann et al., 2020).

Clearing. Clearing is the phase in which the customer is billed. When and how a bill is created depends on the implementation of the mobility service. We identified three categories that influence the price of the ride and the phase of the billing. The first category consists of the initial request parameters, such as the predicted duration of the ride and the booked vehicle class. The second category describes the system's usage when the ride is started: A mobility provider may reduce the cost if a customer utilizes a vehicle with a high sharing-ratio or in times of low system usage. The last category describes the parameters of the actual trip. A ride-sharing provider may reduce the price if the vehicle arrives particularly late or increase it if the customer was repeatedly late. The actual billing may happen before the booking, on pickup, or after drop-off, depending on the business model.

Customer Service. The customer service supports the traveler during all phases of the mobility service, from problems regarding the login, the inquiry of travel information, the booking of itineraries, or difficulties during the travel. Most new problems will, however, arise during travel on autonomous vehicles. User tests in the early stages of system development have shown that interaction with the vehicle gains in importance as soon as the fallback level "human driver" is no longer present to compensate for any weaknesses in the communication design. This observation suggests that the customer service needs to quickly assist the users and address matters that the vehicle's driver usually handles. For this, the customer service must be implemented through the application of the mobility service platform so that the service representative can retrieve the current travel context of the user without needing to inquire about everything from the user. Conversely, the vehicle and mobility application user also expects full transparency for the current progress of the trip and any potential changes (Biermann et al., 2020). It is also crucial that all security important features are also directly usable without interacting with a smartphone. For example, an emergency button needs to be placed inside the vehicle; providing the functionality only inside the application is insufficient.

4 CONCLUSION

In the future, mobility services must be environmentally sustainable while also being flexible enough to fulfill all requirements of travelers. Single travel modes, such as public transit, can never achieve the flexibility of personal transportation such as a private car. Therefore, different travel modes have to be bundled to choose the mode of transportation according to their specific needs for the journey. The integration of mobility service providers on a single platform and the combination of their products offer immense possibilities. These, in turn, result in a high potential for personalizing the mobility service: on the one hand with regard to the composition of the multimodal transport chain, and on the other hand with regard to the individualization of the autonomous mobility service itself, which can be individually adapted to the requirements and needs of different user groups and characteristics.

In this paper, we motivated the need for mobility service platforms and the integration of MoD. In contrast to related work, we have focused on user requirements and derived technical requirements for the integrated services. We have introduced the system architecture of ride-sharing services developed in a German research project to reach this goal. We compared this service with an existing standard for a reference platform for mobility providers. This conceptual integration has shown that integrating autonomous ride-sharing services into intermodal journeys is feasible.

We are mainly interested in researching flexible alternatives to personal cars towards climatic-required environmentally sustainable transportation. In particular, the spatial bundling of mobility services in so-called mobility hubs sounds promising. These mobility hubs may allow users to flexible access a multimodal transportation network, offering similar flexibility as their car. These novel transportation systems may be tested and evaluated with the help of simulation frameworks. Furthermore, we must research the user requirements on tightly integrated intermodal mobility itineraries in greater depth to be capable of developing a demand-oriented and accepted mobility offer.

ACKNOWLEDGEMENTS

This work has been partly funded by the Federal Ministry of Transport and Digital Infrastructure (BMVI) within the funding guideline “Automated and Connected Driving” under the grant number 16AVF2134B. The authors would also like to thank the APEROL consortium for the productive exchange and contributions: https://www.autonomousshuttle.de/en/project-partner/.

REFERENCES

Beutel, M. C., Gökay, S., Jakobs, E.-M., Jarke, M., Kasugai, K., Krempels, K.-H., Ohler, F., Samsel, C., Schwinger, F., Terwelp, C., et al. (2018a). Information system development for seamless mobility. In *Smart Cities, Green Technologies and Intelligent Transport Systems*. Springer.

Beutel, M. C., Gökay, S., Ohler, F., Kohl, W., Krempels, K.-H., Rose, T., Samsel, C., Schwinger, F., and Terwelp, C. (2018b). Mobility service platforms - cross-company cooperation for transportation service interoperability. In *Proceedings of the 20th International Conference on Enterprise Information Systems - Volume 1: ICEIS,*, pages 151–161. INSTICC, SciTePress.

Biermann, H., Philipsen, R., Brell, T., and Ziefle, M. (2020). Shut up and drive? user requirements for communication services in autonomous driving. In *International Conference on Human-Computer Interaction*, pages 3–14. Springer.

Cohen, B. and Kietzmann, J. (2014). Ride on! mobility business models for the sharing economy. *Organization & Environment*, 27(3):279–296.

Flohr, L. A., Janetzko, D., Wallach, D. P., Scholz, S. C., and Krüger, A. (2020). Context-based interface prototyping and evaluation for (shared) autonomous vehicles using a lightweight immersive video-based simulator. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference*, pages 1379–1390.

Gökay, S., Heuvels, A., and Krempels, K.-H. (2019). On-demand ride-sharing services with meeting points. In *VEHITS*, pages 117–125.

Himmel, S., Zaunbrecher, B. S., Ziefle, M., and Beutel, M. C. (2016). Chances for urban electromobility. In *International Conference of Design, User Experience, and Usability*, pages 472–484. Springer.

Hollingsworth, J., Copeland, B., and Johnson, J. X. (2019). Are e-scooters polluters? the environmental impacts of shared dockless electric scooters. *Environmental Research Letters*, 14(8):084031.

Jing, P., Xu, G., Chen, Y., Shi, Y., and Zhan, F. (2020). The determinants behind the acceptance of autonomous vehicles: a systematic review. *Sustainability*, 12(5):1719.

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso González, M. J., and Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges.

Liu, J., Kockelman, K. M., Boesch, P. M., and Ciari, F. (2017). Tracking a system of shared autonomous vehicles across the austin, texas network using agent-based simulation. *Transportation*, 44(6):1261–1278.

Pakusch, C., Stevens, G., and Bossauer, P. (2018). Shared autonomous vehicles: Potentials for a sustainable mobility and risks of unintended effects. In *ICT4S*, pages 258–269.

Philipsen, R., Brell, T., Biermann, H., and Ziefle, M. (2020). On the road again-explanatory factors for the users’ willingness to replace private cars by autonomous on-demand shuttle services. In *International Conference on Applied Human Factors and Ergonomics*, pages 173–185. Springer.

Rayle, L., Dai, D., Chan, N., Cervero, R., and Shaheen, S. (2016). Just a better taxi? a survey-based comparison of taxis, transit, and ridesourcing services in san francisco. *Transport Policy*, 45:168–178.

Shaheen, S. and Cohen, A. (2019). Shared micromoblity policy toolkit: Docked and dockless bike and scooter sharing.

Shaheen, S., Cohen, A., Chan, N., and Bansal, A. (2020). Sharing strategies: carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes. In *Transportation, Land Use, and Environmental Planning*, pages 237–262. Elsevier.

Svanaes, D. and Seland, G. (2004). Putting the users center stage: role playing and low-fi prototyping enable end users to design mobile systems. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 479–486.

Tirachini, A. (2019). Ride-hailing, travel behaviour and sustainable mobility: an international review. *Transportation*, pages 1–37.

Wenzel, T., Rames, C., Kontou, E., and Henao, A. (2019). Travel and energy implications of ridesourcing service in austin, texas. *Transportation Research Part D: Transport and Environment*, 70:18–34.