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Flexible Public Transport - Analysis of User Requirements on Mobility-on-Demand Systems

Alexandra König

Deutsches Zentrum für Luft- und Raumfahrt
Institut für Verkehrssystemtechnik
Standort Braunschweig

DLR Deutsches Zentrum für Luft- und Raumfahrt

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Flexible Bedienformen, Mobility-on-demand-Systeme, autonome Shuttle, Serious Game

Alexandra König
DLR, Institut für Verkehrssystemtechnik, Braunschweig

Flexible Bedienung im öffentlichen Nahverkehr – Analyse der Nutzeranforderungen an Mobility-on-demand-Systeme
Dissertation Technische Universität Braunschweig

Sogenannte *Mobility-on-demand Systeme* (MODS) versprechen eine Transformation des Verkehrssystems hin durch eine Flexibilisierung des öffentlichen Personennahverkehrs (ÖPNV). Das Servicekonzept von MODS unterscheidet sich in großen Teilen vom konventionellem fahrplan- und liniengebundenem ÖPNV. Die flexible Anpassung der Strecke und Zeiten durch den Zu- und Ausstieg weiterer Fahrgäste sind systemimmanente Eigenschaften von MODS. Es kann vermutet werden, dass diese die Wahrnehmung der Zuverlässigkeit von MODS durch die Fahrgäste beeinflussen. Die Literatur bietet nur wenige Ansatzpunkte für die Frage, wie Fahrgäste diesen neuen Service wahrnehmen und bewerten. Ziel dieser Dissertation war es deshalb, zum Verständnis von MODS aus psychologischer Perspektive beizutragen um Anforderungen der Fahrgäste an das flexible Mobilitätsangebot zu beschreiben.

Die Dissertation umfasst vier empirische Studien. In *Studie 1* wurde das Entscheidungsverhalten mithilfe eines Discrete Choice Experiments modelliert um den Einfluss der Serviceeigenschaften von MODS auf die Bewertung des Services zu beschreiben. *Studie 2* basierte auf der Evaluation des Serious Games *B.u.S.*, das entwickelt wurde um das Konzeptverständnis, die Einstellungen und die Nutzungsintention von Spieler/innen für MODS zu erhöhen. *Studie 3* fokussierte den Einfluss des Ridesharing-Konzepts von MODS auf die Bereitschaft zur Nutzung. Ziel der *Studie 4* war es, die Ergebnisse aus Studie 3 um Erkenntnisse zur Relevanz von Informationen über weitere Fahrgäste zu erweitern.

Studie 1 konnte zeigen, dass die Serviceeigenschaften Fahrtzeit, Laufdistanz zum Einstiegsort, Informationsdarbietung, Vorbuchungszeit, Verschiebung der Abfahrtszeit und Fahrpreis eine wichtige Rolle für die Bewertung des Services spielten. Die Berechnung der Zahlungsbereitschaft gab zudem einen Hinweis auf die Bereitschaft, für Verbesserungen des Serviceangebots zu zahlen. Die Evaluation des Serious Games in Studie 2 wies auf deutliche Vorteile des spielerischen Ansatzes für die Erhöhung des Konzeptverständnisses für MODS im Vergleich zur Kontrollgruppe hin. Studie 3 bestärkte und erweiterte die Ergebnisse aus Studie 1 indem sie zeigte, dass die Bereitschaft zum Teilen von Fahrten in MODS von Eigenschaften der Fahrt (Fahrtzeit und Umwegfaktor) und Charakterstika der Fahrgäste (Alter, Geschlecht und Einkommen) abhängt. Studie 4 ergänzte Studie 3 durch das Ergebnis, dass detaillierte Informationen über zusteigende Fahrgäste die Bereitschaft zum Teilen von Fahrten in fahrerlosen MODS erhöhen können.

Auf Basis der Ergebnisse der vier Studien wurde ein Forschungsmodell abgeleitet, das die Flexibilität von MODS berücksichtigt. Abschließend wurden Implikationen und Hypothesen für die nutzerzentrierte Forschung im Rahmen von flexiblen Mobilitätsangeboten abgeleitet, die eine Grundlage für zukünftige Forschung darstellen können.

mobility-on-demand systems, public transport, serious games, choice modelling, autonomous shuttles

(Published in English)

Alexandra König
DLR, Institut für Verkehrssystemtechnik, Braunschweig

Flexible Public Transport - Analysis of User Requirements on Mobility-on-Demand Systems

Dissertation Technical University Brunswick

App-based *mobility-on-demand systems* (MODS) promise a transformation towards a more sustainable mobility by offering a flexible public transport. The service concept of MODS is to a large extent very different from conventional scheduled transport. As an example, the adaptability of routes, times and sudden divergence from planned routes, to pick-up and drop-off passengers, are characteristics inherent of MODS that are in contrast to the service quality aspect of reliability of conventional public transport. Scientific literature gives insufficient information on the issue of how users perceive and assess these new services. The aim of this dissertation is to contribute to the understanding of the users' requirements, as well as drivers and barriers for using MODS.

This dissertation comprises four empirical studies to investigate the factors that affect the perception and assessment of MODS. In *Study 1*, a choice modelling approach based on a discrete choice experiment was used to identify which service characteristics affect travellers' appraisal of MODS. *Study 2* introduces the serious game *B.u.S.*, that was developed and used to improve players' knowledge, attitude and willingness to use MODS. The effectiveness of the serious game to impart knowledge about the service concept of MODS and to raise awareness about the usefulness of the service was assessed in an evaluation study. *Study 3* focused on the impact of the ridesharing concept on travellers' willingness to use MODS. *Study 4* complemented the findings of *Study 3* by investigating the effects of information provision about fellow travellers' characteristics, such as name or gender, on individuals' compensation demands for sharing rides.

Study 1 revealed the importance of the six service attributes of travelling time, walking distance, information provision, time of booking, shift of departure time, and fare on the respondents' appraisal of the service concept. The calculation of the willingness to pay gave an indication of the respondents' wish for an improvement in the quality of the service offered. The evaluation study of the serious game in Study 2 found clear indications of beneficial effects of the serious game on individuals' conceptual comprehension and understanding of MODS. Study 3 verified and expanded the findings of Study 1 by showing that the willingness to share rides in autonomous MODS depends on specific characteristics of each trip (travel time and detour factor) as well as personal characteristics (age, gender and income). Study 4 supplemented the findings of Study 3 by revealing a beneficial effect of detailed information about fellow travellers on traveller's willingness to share rides in autonomous MODS.

Based on the findings of the four studies, a research model to approach individual's assessment of the flexibility of public transport systems is derived. Implications for the user-centred research on flexible mobility are derived in the form of hypotheses that can guide further research.

Flexible Public Transport -

Analysis of User Requirements on Mobility-on-Demand Systems

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Content

List of Abbreviations

AMODS = autonomous mobility-on-demand systems

DRT = demand-responsive transport

ICT = information and communication technology

ITF = International Transportation Forum

MODS = Mobility-on-demand systems

OECD = Organisation for Economic Co-operation and Development

PBC = Perceived Behavioural Control

SA = Situation Awareness

SP = Stated Preference

TAM = Technology Acceptance Model

TPB = Theory of Planned Behaviour

UTAUT = Unified Theory of Acceptance and Use of Technology

WHO = World Health Organization

WTA = Willingness to accept

WTP = Willingness to pay

Summary

Contemporary society faces the challenge of mitigating the negative effects of motorized individual transport, which includes greenhouse gas emissions, noise, accidents and traffic congestion. App-based *mobility-on-demand systems* (MODS) promise a transformation towards a more sustainable mobility by offering a flexible public transport as an alternative to private motorized transport. As new MODS flourish and spread quickly, it is important to understand how they affect individual travel patterns and transportation systems. The service concept of MODS is to a large extent very different from conventional scheduled transport. As an example, the adaptability of routes, times and sudden divergence from planned routes, to pick-up and drop-off passengers, are characteristics inherent of MODS that are in contrast to the service quality aspect of reliability of conventional public transport. Scientific literature gives insufficient information on the issue of how users perceive and assess these new services. From a scientific perspective, the novelty of MODS requires the adaption of established behavioural models and theories to study the flexibility of the system. The aim of this dissertation is to contribute to the understanding of the users' requirements, as well as drivers and barriers for using MODS. This dissertation aims to fill the research gap that opens up with regard to users' perception and assessment of MODS, especially their flexible service concept. This dissertation thereby aims to contribute to the development of theories based on empirical studies.

This dissertation comprises four empirical studies to investigate the factors that affect the perception and assessment of MODS. In *Study 1*, a choice modelling approach based on a discrete choice experiment was used to identify which service characteristics affect travellers' appraisal of MODS. *Study 2* builds upon *Study 1* by using the results of the preference modelling for imparting the service concept of MODS and the service characteristics to the users. For this purpose, the serious game *B.u.S.* was developed and used to improve players' knowledge, attitude and willingness to use MODS. The effectiveness of the serious game to impart knowledge about the service concept of MODS and to raise awareness about the usefulness of the service was assessed in an evaluation study. *Study 3* focused on the impact of a specific service characteristic, the ridesharing concept on travellers' willingness to use MODS. The purpose of *Study 3* was to examine the effects of a flexible travel time and a variable detour factor as the specific service characteristics of MODS on the willingness to share rides in autonomous MODS. *Study 4* complemented the findings of *Study 3* by a sociopsychological perspective on the ridesharing concept in autonomous MODS. In more detail, *Study 4* investigated the effects of information provision about fellow travellers' characteristics, such as name or gender, on individuals' compensation demands for sharing rides. Altogether, the four independent, yet closely related studies of the dissertation shed light

on the user's perception of MODS by using and developing theories and models of behavioural science based on flexible MODS.

The results of each of the four studies will be analysed jointly to understand the potential user requirements on MODS and thereby expand the state of research. Looking at the results of each study separately, *Study 1* revealed the importance of the six service attributes of travelling time, walking distance, information provision, time of booking, shift of departure time, and fare on the respondents' appraisal of the service concept. The calculation of the willingness to pay gave an indication of the respondents' wish for an improvement in the quality of the service offered, for example a shorter walking distance to the pick-up point. The evaluation study of the serious game in *Study 2* found clear indications of beneficial effects of the serious game on individuals' conceptual comprehension and understanding of MODS. *Study 3* verified and expanded the findings of *Study 1* by showing that the willingness to share rides in autonomous MODS depends on specific characteristics of each trip (travel time and detour factor) as well as personal characteristics (age, gender and income). *Study 4* supplemented the findings of *Study 3* by revealing a beneficial effect of detailed information about fellow travellers on traveller's willingness to share rides in autonomous MODS. Accordingly, full profile information involving a picture, the name and a rating of the fellow traveller was found to reduce the compensation demands for sharing rides.

The overall goal of this dissertation is to start filling the gap in the academic literature concerning the perception and appraisal of MODS and users' willingness to adopt them and thereby to complement behavioural theories. Based on the findings of the four studies, a research model to approach individual's assessment of the flexibility of public transport systems is derived. This model adds to existing models such as the Theory of Planned Behaviour (Ajzen, 1991) and the Technology Acceptance Model (Davis, 1985) to include understanding of the flexibility dimension of MODS. Based on the findings of the four studies, implications for the user-centred research on flexible mobility are derived in the form of hypotheses that can guide further research.

1. Introduction

1.1 Transformation of Individual Mobility

Individual mobility is currently undergoing a transformation (Shaheen, Totte, & Stocker, 2018). This process is primarily shaped by three aspects: technology-driven development trends (Marsden, Dales, Jones, Seagriff, & Spurling, 2018), changing mobility needs (Hammer & Scheiner, 2006; Wockatz & Schartau, 2015) and the call for more sustainable transport by government policy and society (ITF, 2015a; WHO, 2018).

First, two main objectives guide technology-driven development trends in the field of public transport: the transition to renewable energy (German: *Energiewende*), and the transformation of the public transport sector (German: *Verkehrswende*) to achieve carbon neutrality (Hochfeld et al., 2017). These trends shape the market offer for customers by the emergence of new service providers and services, such as car-hailing services and shared electric scooters (Moreau et al., 2020; Sun, Zhang, & Shen, 2018).

Second, changing mobility needs are a consequence of increasingly unsteady daily schedules due to differentiation and pluralisation of lifestyles (Marsden et al., 2018; Scheiner & Kasper, 2017). Accordingly, travellers seek out mobility services that take their spontaneous and highly flexible mobility needs into account (Hammer & Scheiner, 2006; Wockatz & Schartau, 2015). Changing lifestyles and the demand that needs are answered immediately are key drivers of changing mobility needs (Alonso-Mora, Samaranayake, Wallar, Frazzoli, & Rus, 2017). The transformation is also characterised by an increasing preference for renting rather than buying products, the so called *servitisation* (Standing, Standing & Biermann, 2019) or access to mobility instead of ownership of vehicles (Liyanage, Dia, Abduljabbar & Bagloee, 2019).

Third, a considerable number of politicians as well as members of the scientific community and civil society have repeatedly called for a rethinking of the current mobility paradigm towards more sustainable transport modes (ITF, 2015a; WHO, 2018). Private cars are indisputably the dominant transport mode in passenger transportation in developed countries due to their benefits for providing independent, individual, and flexible mobility (Kuhnimhof & Nobis, 2018). However, car-centred transport has reached a tipping point that calls for a radical rethinking of the individual's mobility needs (Freudendal-Pedersen, 2016). It is a clearly desirable accepted goal to keep the negative side effects and external costs of transportation e.g., due to congestions, accidents and air pollution, to a minimum (ITF, 2015a). Individual mobility is thus challenged to bundle up traffic demands to handle an increasing and diversified mobility demand (König & Grippenkoven, 2017).

The preceding paragraphs show that individual mobility is undergoing considerable changes. To conclude, the ongoing transformation of individual mobility, based on technology-driven and human-centred trends, opens up the field for new mobility services that promise individual mobility away from the private car. As a consequence, shared and flexible transport services are emerging at the interplay of this social, technological, and economic transformation.

The terminology of these new mobility services is far from self-explanatory and often the boundaries between the service concepts are blurred (Sprei, 2018). Terms such as ridesharing and ridehailing are often used interchangeably by service providers, in the press or by researchers, yet, they describe fundamentally different service concepts. Table 1 provides an overview of the most common terms for new motorized mobility services and differentiates between the service concepts.

These new transport services represent the attempt for a shift towards the collectivisation of individual motorised transport on the one hand and the individualisation and flexibilisation of public transport on the other hand (Liyanage et al., 2019; Perret, Fischer & Frantz, 2018).

From one side of the transformation, individual motorised transport by privately owned cars opens up to non-commercial peer-to-peer *ridesharing* schemes (Olsson, Maier & Friman, 2019) and commercial *ridehailing* services (Alemi, Circella, Handy & Mokhtarian, 2018). Ridesharing combines the flexibility and speed of private cars with reduced costs and beneficial effects for the transport system and the environment due to the reduction of the number of cars on the road because the rides are shared with other passengers (Chan & Shaheen, 2012). Unlike ridesharing schemes, ridehailing is motivated by fare income and usually driver and passenger do not share the same destination (Clewlow & Mishra, 2017; Olsson, Maier, & Friman, 2019; Shaheen, 2016). Ridehailing provides an on-demand app-based transport service carried out by drivers who use their private cars to answer the requests of users (Henao, 2017). Furthermore, carsharing offers short-term rental of vehicles that are successively shared with other users (Shaheen & Cohen, 2013).

Another aspect of the transformation is characterized by the individualisation and flexibilisation of public transport (Liyanage et al., 2019). Recently, mobility-on-demand systems (MODS), also called *ridepooling*, have emerged as new transport services at the intersection between individual and public transport. In this way, MODS make use of digitalisation and the rapid spread of information technology and routing algorithms that matches rides of travellers and so provides flexible public transport to customers (ITF, 2019).

To conclude, the emerging new mobility services of the last decade represents a shift towards the collectivisation of individual motorized transport on the one hand and the individualization of public transport on the other hand with a great degree of variations between the service concepts of these systems and the proposed benefits for the users (Liyanage et al., 2019).

Table 1

Differentiation of new mobility services according to their service concept

	New mobility services			
	Carsharing	Ridehailing	Ridesharing	Mobility-on-demand
Synonym	-	Ridesourcing, transportation network companies	Carpooling	Ridepooling, ridematching
Definition	Short-term rental of vehicles for short-term use based on a return-to-base or free-floating scheme	Point-to-point transportation comparable to traditional taxis but ordered solely via smartphone app	Cost splitting between people who have similar itineraries and time schedules and match their routes by sharing a short or long, regular or one-off ride that is taking place anyway	Flexible public transportation service without fixed route, times and stops but real-time routing according to the ride requests of travellers
Business model	Commercial, business-to-consumer (B2C)	Commercial, business-to-consumer (B2C)	Non-commercial peer-to-peer	Commercial, business-to-consumer (B2C), public-private partnership or public funded
Vehicle ownership	Company owned fleet	Private person	Private person	Company owned fleet
Examples	*Car2Go, DriveNow*	*UberX*, *GrabCar*	*GrabHitch*, *BlaBlaCar*	*Kutsuplus, Moia*
References	Shaheen & Cohen (2013)	Alemi (2018), Henao (2017), Tirachini (2019)	Chan & Shaheen (2012), Olsson, Maier, & Friman, (2019)	Shaheen & Cohen (2018), Liyanage et al. (2019), Weckström et al., (2018)

1.2 Mobility-on-Demand Systems

MODS offer a public transport service without fixed schedules and predefined stops. By operating exclusively according to the actual demand of passengers, MODS provide a more flexible and customisable service than scheduled transport systems (König, Wegener, Pelz, & Grippenkoven, 2017). MODS were expected to play an important role in creating a future sustainable passenger transport as they could contribute to the policy's key goal to shift travellers from low-occupancy private vehicles to shared public transport (Liyanage et al., 2019). MODS waive fixed stops, routes, and timetables in favour of flexible demand-responsive routing depending on people's real-time transport requests in the "here and now". (Viergutz & Brinkmann, 2018). Thus, route changes are a system-inherent service characteristic as the arrival and departure of further passengers requires deviations from the route (ITF, 2019). In contrast to other shared mobility concepts such as ridehailing, professional drivers conduct the rides with a vehicle of which can be a conventional passenger car or a mini-bus with 10 or more passenger seats (Liyanage et al., 2019). To summarize, this dissertation adapts the following definition of mobility-on-demand according to Beiker (2016), Liyanage et al., (2019), and Weckström et al., (2018):

Mobility-on-demand services are a form of public transport offering demand-responsive transportation based on a routing algorithm that matches ride request of travellers via digital platforms and provides temporal and spatially flexible mobility by adapting its route to the actual demand which might entail detours.

Such MODS have been operating under the service concept of *demand-responsive transport* (DRT)*, paratransit* or *dial-a-ride service*, especially in rural areas for decades (Nelson & Phonphitakchai, 2012; Ronald, Thompson, & Winter, 2015). Whereas DRT mainly replaces scheduled public transport in sparsely populated areas where such a system is not sustainable, MODS now emerge mainly in major cities. A bottleneck that has prevented a widespread use and cost-efficient operation of DRT concepts was the high effort for planning, routing, and billing for the operators (ITF, 2014). Furthermore, the need for early reservations, a lack of in-time travel information and the unpredictability of the trip's duration for the passengers have been usage barriers of DRTs (ITF, 2014). Due to the ongoing progress in digitalisation, especially information and communication technology (ICT), DRTs have a very promising future and currently evolve towards more flexible and efficient MODS (ITF, 2014).

To give an overview of existing MODS is a challenge as the terminology of shared mobility has not yet been not standardized (Shaheen & Cohen, 2018). The fast pace of new launches and the diversity of service concepts of MODS, e.g., serving stops or providing a door-to-door operation, contribute to the lack of clarity in the market. In Germany, service providers such as MOIA (Gilibert, Rogas, & Rodriguez-Donaire, 2017) or public transport companies such as

Berliner Verkehrsbetriebe (Ullrich, 2019) operate MODS. There are examples of MODS, such as the Finnish *Kutsuplus* (Weckström et al., 2018), that have already ceased operating. As well, several research projects have started over the last few years, for example *Reallabor Schorndorf,* that prepared and monitored the introduction of a new MODS (Gebhardt, Brost, & König, 2019). However, a comprehensive overview of the discontinued, existing and planned MODS is lacking.

MODS are an attractive supplement for public transport because they are considered as user-centred and sustainable transport services in first studies (Alonso-Mora et al., 2017; Gunay, Akgol, Andréasson, & Terzi, 2016; Henao, 2017; ITF, 2016; ITF, 2018a; Knie & Ruhrort, 2020; Tirachini & Gomez-Lobo, 2017). Among the proposed benefits of MODS are increased levels of accessibility and connectivity of public transport and, thus, improved social equity (ITF, 2018a). Additionally, MODS could increase accessibility of mobility for persons with reduced mobility (Liyanage et al., 2019) as they provide more user-centred mobility by adapting the supply to the actual demand of the users (Alonso-Mora et al., 2017). Recent studies have attributed several beneficial effects of MODS on sustainable transport (Alonso-Mora et al., 2017; Chandra, Bari, Devarasetty, & Vadali, 2013; Gunay et al., 2016; Henao, 2017; ITF, 2016; ITF, 2018a; Knie & Ruhrort, 2020; Tirachini & Gomez-Lobo, 2017). In more detail, MODS offer the potential to complement public transport as a feeder system for first and last mile transport (Chandra et al., 2013) and thus to replace motorized individual transport (Gunay et al., 2016). In a recent survey study, Knie and Ruhrort (2020) revealed that MODS were attributed the potential to facilitate urban mobility without private car and increase the willingness of users to abolish their car. Adding to this, results of simulation studies indicated substantial benefits of MODS for the cities surveyed in terms of reduced congestion and emissions (Alonso-Mora et al., 2017; ITF, 2016; ITF 2018a; Martinez, Correia, & Viegas, 2015). The specific effects were of particular importance, when the rides were shared with a high number of other travellers (Alonso-Mora et al., 2017; Henao, 2017; Tirachini & Gomez-Lobo, 2017). Accordingly, Shaheen and Cohen (2018) stated that “one of the most significant advantages of shared mobility is pooling the rides of passengers with similar destinations in the same vehicle” (Shaheen & Cohen, 2018, p. iii). To conclude, the demand-responsive operation concept of MODS promises several beneficial effects for user satisfaction, efficiency and sustainability of the transport system.

1.3 Autonomous Mobility-on-Demand Systems

The penetration of mobility-on-demand services is expected to grow further with the advent of autonomous vehicles of SAE level 5. This describes a technological status, in which the autonomous driving feature can control a vehicle under all conditions (SAE, 2016). These autonomous vehicles are expected to change the landscape of individual mobility and to fundamentally transform our transport system and shape our lives, infrastructures, and cities (Friedrich, 2016; Greenblatt & Shaheen, 2015; ITF, 2015a). Even though, autonomous mobility is still in its infancy, "shareable networks of autonomous electric vehicles, in particular, are reported to hold great promise for addressing the urban mobility challenges and promoting sustainable transport" (Dia & Javanshour, 2017, p. 287). Greenblatt and Shaheen (2015) pointed to potential synergies between autonomous driving and MODS. Hence, a combination of autonomous driving technology and MODS can be a meaningful connection addressing the mobility challenges faced especially by dense urban cities (Fraedrich, Beiker, & Lenz, 2015). Consequently, the participants of a qualitative study by Salonen and Haavisto (2019) expected the greatest benefit from an on-demand service provided by an autonomous bus. To conclude, autonomous driving technology will most probably facilitate the dissemination of MODS (Krueger, Rashidi, & Rose, 2016).

According to studies, the emergence and widespread adoption of autonomous MODS (AMODS) can be a turning point for public mobility (Atasoy, Ikeda, Song, & Ben-Akiva, 2015; COWI & PTV Group, 2019; Shen, Zhang, & Zhao, 2018). However, studies, such as the simulation studies of Spieser et al., (2014) for the city of Singapore and the ITF-study (2015a) for Lisbon showed, that the expected effects of autonomous driving technology on the public transport system depend on the type of ownership and use (see Figure 1). Accordingly, privately-owned and used autonomous vehicles can contribute to an increased vehicle demand, growing vehicle kilometres travelled (VKT), and higher local emissions compared with the current transport system (COWI & PTV Group, 2019; ITF, 2015b; Trommer et al., 2016; World Economic Forum, 2018). In contrast, shared-used autonomous vehicles will contribute to decreased VKT, less parking space needed and fewer local emissions, especially when they are integrated in public transport system (COWI & PTV Group, 2019; Dia & Javanshour, 2019; ITF, 2015a; Spieser et al., 2014). Thus, studies recommend a ridesharing scheme for future autonomous vehicles to increase occupancy rates of the vehicles (Fagnant, Kockelman, & Bansal, 2015; Friedrich, 2015, Greenblatt & Shaheen, 2015). Lavieri and Bhat (2018) wrote: "there is growing evidence that ridesharing will be a key element to ensure a sustainable future to urban transportation in an AV [AV = autonomous vehicles] future" (Lavieri & Bhat, 2018, p. 29). To conclude, a future autonomous driving scenario will only contribute to a more efficient, sustainable, and safe transportation system if vehicles are used in a shared manner to ensure higher occupancy rates than individually used autonomous vehicles (COWI & PTV Group, 2019; Friedrich, 2015, Greenblatt & Shaheen, 2015; Lavieri & Bhat, 2018).

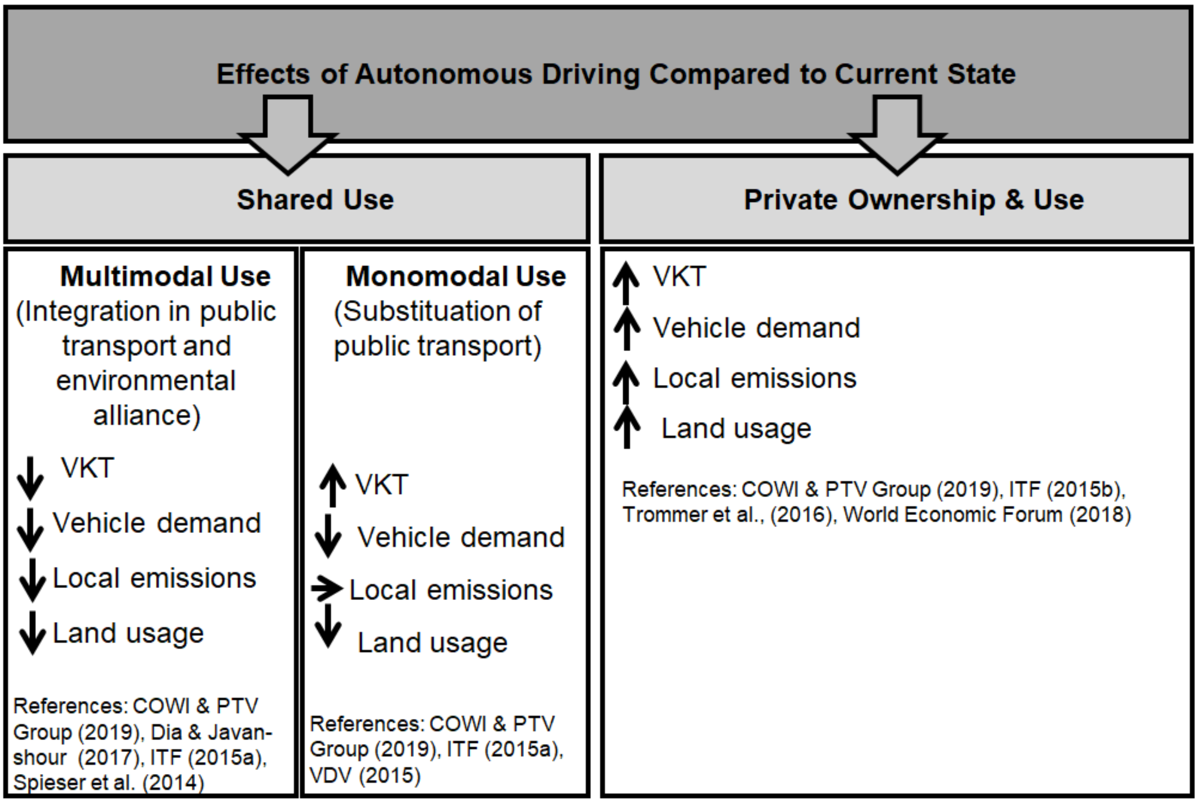

Figure 1. Expected effects of autonomous driving on the transport system adapted from Hochfeld et al. (2017).
Note. VKT = vehicle kilometers travelled.

2. Theoretical Framework

To give a theoretical framework for this dissertation, first, the key scientific terms in relation to the service quality of transport systems and the related user needs are defined. Second, theoretical models are introduced that try to describe the causal relationships and interdependencies between these terms and reflected for their scientific applicability to approach the user perspective on MODS

2.1 Service Quality and User Needs

Transportation research has shown that travellers' choice for or against a transportation mode strongly depended on the subjective assessment of the service quality (De Oña et al., 2016; Lai & Chen, 2010). Service quality is thereby assessed by a comparison of expectations and the actual experiences regarding a service (Gao, Rasouli, Timmermans, & Wang, 2018). Service quality characteristics, such as travel time, price or reliability, were shown to be important determinants for the assessment of the service quality (Bourgeat, 2015; De Oña et al., 2016). A beneficial assessment of the service quality of transport services resulted in higher user satisfaction and increasing use (De Oña et al., 2016; De Vos, 2019).

From a psychological perspective, user satisfaction with transport services can also be described based on Maslow's (1943) *Hierarchy of Needs* (Allen, Muñoz, & de Dios Ortúzar, 2019; Jipp, 2018; Mokhtarian, Salomon, & Singer, 2015). According to the Hierarchy of Needs, individuals act to fulfil their needs, which are organized into a hierarchy with the most primary needs (physiological needs) at the bottom and the highest-order needs (self-actualization) at the top of the hierarchy. The theory suggested that higher-order needs were only then relevant if the more basic needs were fulfilled. Transport modes that fulfil the need for esteem, for example by acting as a status symbol, only gained importance if lower-order needs were fulfilled. A good example of a lower order need is that of safety (Mokhtarian, Salomon, & Singer, 2015). It is thus an important challenge for transport services to fulfil basic needs first.

The feeling of safety is one of the basic needs of humans. The perception of personal safety, *perceived safety*, had an important impact on public transport use (Delbosc & Currie, 2012). The perceived safety in public transport was shown to be linked to the perceived likelihood of facing risks, such as the risk of accidents, violent crime, non-violent crime (e.g., drug use) or the risk of infections (Friman, Lättman, & Olsson, 2020). Perceived safety in public transport can be improved by different measures, such as promoting positive social interactions (Currie, Delbosc, & Mahmoud, 2013) and providing good quality information (Friman, Lättman, & Olsson, 2020).

The provision of information about the service quality, e.g., frequency of service, and real-time information about the service, has been shown to be important for public transport users (Bourgeat, 2015; Redman et al., 2013). Information plays an even more important role in dynamic contexts (Albers, 2004; Sonnenwald & Pierce, 2000). In dynamic contexts, information supports the individual's Situation Awareness (SA). The concept of SA is a mental representation that involves not only a representation of the situation but also expectations about its future development (Endsley, 1995). User's SA can be facilitated by mental models (Endsley, 1988) which are the individual's view of how something works (Norman, 2014). While research regarding SA and mental models is well advanced in the field of transport operators and drivers (c.f. Jipp & Ackerman, 2016; Thomas-Friedrich & Grippenkoven, 2017), research in the context of transport passengers is lacking. However, especially for flexible public transport services, such as MODS, the overall conceptual understanding and formation of a mental model as well as the SA in specific use cases can be regarded as important facilitators for their adoption. In conclusion, information about the service concept can probably support the formation of a mental model whereas real-time information might support users' SA.

2.2 Theoretical Models

There are various approaches to describe and explain mobility behaviour and transport mode choice. In the following, five theoretical approaches are introduced: rational choice theory, attitude-based theories, technology acceptance models, diffusion of innovation and decision-making theory. In the following, these theoretical models are briefly introduced and assessed regarding their suitability to approach the user perspective on MODS.

Rational Choice Theory

In rational choice theory, it is assumed that individuals choose the option that promises the maximum subjective utility (Scott, 2000). In the context of mobility, this means that individuals base their choices on minimising the time and cost of travel to maximise utility (Keyes & Crawford-Brown, 2018). The underlying Utility Theory has been a widely accepted paradigm describing human behaviour in transport (Van De Kaa, 2010). Rational choice theory assumes that individuals have all the information needed for the choice, act under specific constraints, such as time or costs and have stable preferences (Hindmoor & Taylor, 2015).

In recent years, rational choice theory has increasingly experienced criticism due to its high level of abstraction that ignores the interplay of economic, spatial, ecological, social, and psychological aspects (Freudendal-Pedersen, 2016) and its neglect of illogical influences such as habits and impulsiveness (van Acker, van Wee, & Witlox, 2010). Moreover, rational choice theory assumes that human action and decision-making is guided exclusively by utility-maximizing motives, thus incapable of explaining social norms, such as altruistic behaviour (Scott, 2000). However, many characteristics of a product or choice are often valued affectively with a psychological value rather than rationally as demonstrated for example in car ownership studies (e.g., Steg et al., 2005). Studies concerning the subjective value of time (Tversky & Kahneman, 1981), cognitive heuristics (Gigerenzer & Brighton, 2009), and anchoring and framing effects (Kahneman, 2011) proved that human decision-making has not always been based on a rational appreciation process. Thus, behavioural models try to close the gap that is left open by rational choice models (e.g., Möser & Bamberg, 2008, Nordfijaern & Rundmo, 2015).

For MODS, it can be assumed that rational choice theory does not meet their complexity and flexibility because it disregards essential aspects, such as pro-social behaviour of sharing rides. Furthermore, the assumption that individuals have all the information needed for the choice is hard to meet in the context of MODS because of the novelty of the service concept that results in a lack of information regarding the service characteristics. A rational choice based on an informed decision-making process is thus impeded. To conclude, rational choice theory is of rather little use to explain choice behaviour in the context of MODS.

Attitude-based Theories

Attitude-based theories take norms, beliefs and attitudes into account. Attitude-based models, such as the *Reasoned Action Approach* (Fishbein & Ajzen, 2011) and the *Theory of Planned Behavior* (TPB, Ajzen, 1991) have been proven to predict accurately travel behaviour and are one of the most widely employed behavioural models in transportation research (cf. Bamberg, Fujii, Friman, & Gärling, 2011; Gardner & Abraham, 2008; Gärling, Gillhol, & Gärling, 1998; Heath & Gifford, 2002). As predicted by the models, a positive attitude towards the intended behaviour, which was defined as an "individual's overall affective reaction to using a system" (Venkatesh et al., 2003, S. 455), strengthened the intention to take part in a new service (Murray et al., 2010, Nilsson & Kuller, 2000).

Besides its wide distribution and application (Armitage & Conner, 2001), attitude-based models such as the TPB have also been the target of criticism and debate (Ajzen, 2011). Three important restrictions of attitude-based models are briefly presented. First, the TPB was criticized because it neglects the role of situational constraints and habits (Klöckner & Blöbaum, 2010). Second, as another point of criticism, studies recurrently report on boundaries between motivational and action phases that separate the intention stage from the stage, resulting in a so-called *attitude-behaviour gap* (Byrka, 2009; Claudy, Peterson, & O'Driscoll, 2013; Kollmuss & Agyeman, 2002; Vermeir & Verbeke, 2006). Thus, attitude-based models were expanded to include other factors such as *performance difficulty* to determine the attitude-behaviour relationship (Stern, 2000). Third, another shortcoming of attitude-based theories lies in their strong emphasis on an individual's behaviour that is based on previous experiences and attitudes implied by a certain type of behaviour (Bamberg, Ajzen & Schmidt, 2003).

For the application of attitude-based models to MODS the lack of first-hand experiences with MODS and especially autonomous MODS should be considered. In this context, the personality trait *openness to experience* (McCrae & John, 1992) might play an important role in the general openness to try out new products and services, such as MODS. It can be further assumed that individuals have no specific attitudes concerning these systems but transfer their subjective appraisal from comparable transport systems, such as bus transport or ridesharing services to the unknown system. User acceptance research showed that there was a difference between the prospective assessment of a product or service before and after first use (Distler, Lallemand & Bellet, 2018; Epprecht, Von Wirth, Stünzi, & Blumer, 2014; Schuitema, Steg, & Forward, 2010). Hence, research discriminates between *acceptance* (subjective appraisal after previous experience) and *acceptability* (subjective appraisal before having used it, Schade & Schlag, 2003). The missing first-hand experiences will presumably lead to the challenge of reaching a sufficient level of users' immersion in the new mobility concepts, especially for driverless systems (Distler, Lallemand, & Bellet, 2018). To conclude, attitude-based models are valuable frameworks for the study of user choice behaviour in the context of mobility. Yet, these models reach their limits for the analysis of new transport systems and must be adapted to describe user behaviour in the context of MODS.

Technology Acceptance Models

Technology acceptance models, that have their origin in predicting ICT usage, were applied to assess individuals' willingness to use new transport systems, such as carsharing (Fleury, Tom, Jamet, & Colas-Maheux, 2017), e-bikes (Wolf & Seebauer, 2014), mass rapid transit systems (Chen & Chao, 2011), and autonomous shuttle busses (Madigan et al., 2016). The *Technology Acceptance Model* (TAM, Davis, 1985) and the *Unified Theory of Acceptance and Use of Technology* (UTAUT, Venkatesh et al., 2003) are two prominent examples for technology acceptance models. According to the TAM, the concepts of *Perceived Ease of Use* and *Perceived Usefulness* are the most important factors in explaining technology use (Davis, 1985). The UTAUT, however, is based on four key concepts: *Performance Expectancy*, *Effort Expectancy*, *Social Influence* and *Facilitating Conditions* that affect *Use Behaviour* directly or indirectly through *Behavioural Intention* (Venkatesh et al., 2003).

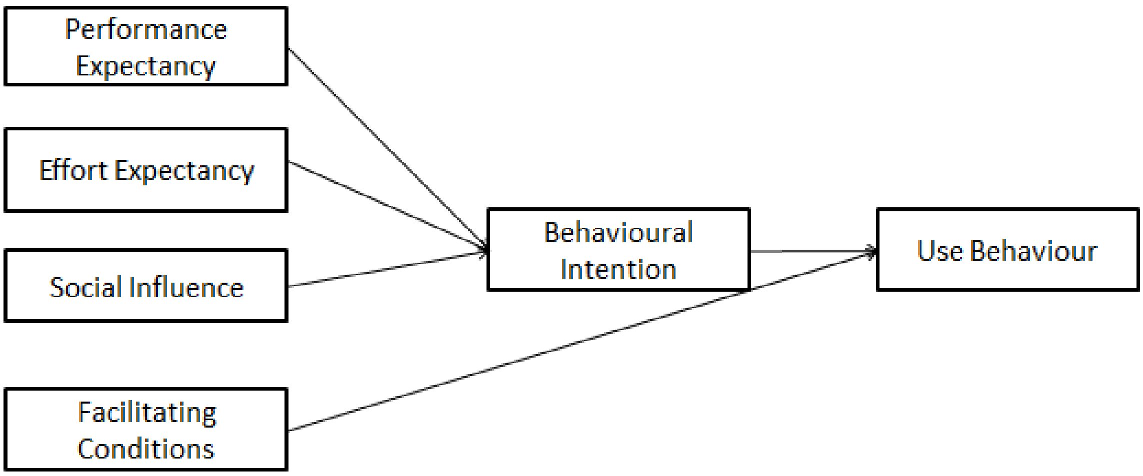

Figure 2. Main constructs of the Unified Theory of Acceptance and Use of Technology (adapted from Venkatesh et al., 2003, republished with the permission of Copyright Clearance Center)

In spite of their popularity (Marangunić & Granić, 2015; Williams, Rana, Dwivedi, & Lal, 2011), technology acceptance models often fail to explain a high share of actual use behaviour (Madigan et al., 2017). TAM and UTAUT often account for no more than 30% to 50% of the variance in use of information systems and information technology, which is the original focus of the models (Dwivedi, Rana, Jeyaraj, Clement, & Williams, 2019; Legis, Ingham, & Collerette, 2003), indicating that relevant factors are not included in the models. In the context of autonomous bus shuttles, the application of the UTAUT resulted in an explained variance of no more than 22% (Madigan et al., 2017). Thus, technology acceptance models are subjects of frequent adjustments that include variables related to human and social change processes and innovation diffusion among others (Dwivedi et al., 2019; Madigan et al., 2017; Venkatesh & Davis, 2000; Venkatesh et al., 2012; Wang, Wang, Wang, Wei, & Wang, 2018). In a recent study, Panagiotopoulos and Dimitrakopoulos (2018) extended the TAM with the concepts of *Perceived Trust* and *Social Influence* and showed that the Perceived Usefulness is the strongest predictor on behavioural intentions to have or use autonomous vehicles.

For MODS, technology acceptance models such as TAM and UTAUT offer the advantage of incorporating the concepts of *perceived* or *expected users' assessments*, thus taking into account the lack of first-hand experiences and unfamiliarity with the service concept. Yet, the TAM is based on the assumption that the motivational process of system use and adoption is shaped by the features and capabilities of the system (Fig. 3). However, there is a paucity of research into which service characteristics of MODS contribute to technology acceptance, such as *Performance Expectancy* or *Effort Expectancy*. The determinants of these constructs are still unresearched. Individuals will form early perceptions of perceived ease of use or usefulness of a system based on their general beliefs regarding these services and related well-known systems (Venkatesh, 2000). Yet, it is unclear, which systems are used for this comparison. To conclude, technology acceptance models represent a promising theoretical framework to assess individuals' willingness to use MODS. However, research is needed to study the effects of system features of MODS on user perception, such as reliability and availability.

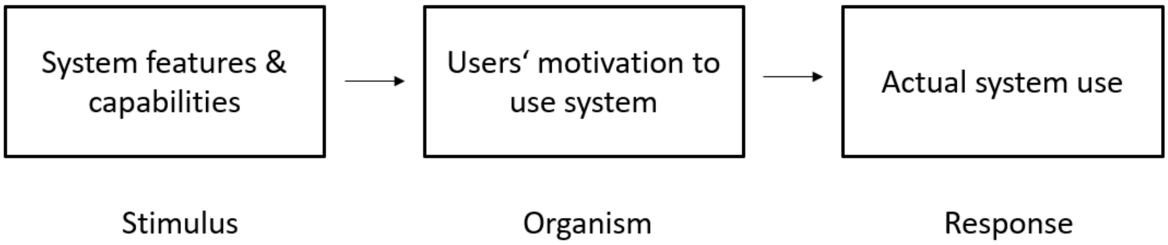

Figure 3. Motivational process of system use and adoption (adapted from Davis, 1985, p. 10, republished with the permission of MIT Press)

Diffusion of Innovation Theory

A worthwhile approach for predicting mobility choices and approaching the adoption process for transport innovations is Roger's theory of *Diffusion of Innovation* (Rogers, 2010). The theory describes the adoption of innovations as a process of five different stages: knowledge, persuasion, decision, implementation and confirmation (Rogers, 2010). The theory also considers prior conditions of the innovation diffusion process such as felt needs, previous practice, and norms of the social system (Rogers, 2010). As shown in Figure 4, the knowledge stage is the first phase of the diffusion of innovation process. This phase is of particular relevance for the introduction of new systems as it builds the basis for the subsequent steps of the adoption process. Accordingly, it can be argued that an awareness of the new service and a comprehensive understanding of the service concept are necessary prerequisites for the following stages. In this step, an individual learns about the existence of innovation and gains information about it. During this phase, individuals attempt to determine how and why the innovation works (Rogers, 2010). Thus, besides encouraging a *how-to* experience also a *know-why* experience is seen as an essential task for technology and service providers (Seemann, 2003). In the following phases, the individual forms an attitude toward the innovation (persuasion) and decides on the question whether to adopt or reject the innovation (decision). Subsequently, the innovation is put into use (implementation) and the behaviour is reinforced (confirmation).

The Diffusion of Innovation Model has been used in the context of mobility to study the acceptance and diffusion of electric vehicles (Peters & Dütschke, 2014), carsharing (El Zarwi, Vij, & Walker, 2017), bikesharing (Parkes, Marsden, Shaheen, & Cohen, 2013) and autonomous vehicles (Talebian & Mishra, 2018). Notwithstanding its popularity (Greenhalgh et al., 2005), the Diffusion of Innovation Model reached its limits in describing the adoption process in complex and interrelated systems (Lyytinen & Damsgaard, 2001). Furthermore, the theory is more appropriate for explaining how an innovation diffuses rather than why it was chosen by the individual (Parkes et al., 2013).

In all conscience, the theory has not yet been applied to study the adoption of MODS. However, the stage model of the theory makes it promising for the assessment of user adoption of MODS. However, the processes through the five stages require a detailed analysis. For example, it is not explained in detail, how the individual forms a favourable or unfavourable attitude towards the innovation in the phase of persuasion. For MODS, it can be assumed that the characteristics *relative advantage*, *compatibility* and *complexity* play an important role in the persuasion stage. Yet, more research is needed to study the meaning of these characteristics in the context of MODS. In this context, especially the combination of the Diffusion of Innovation Model and technology acceptance models as for example proposed by Lee, Hsieh, and Hsu (2011) can be a promising way to study the adoption of these new systems. To summarize, Diffusion of Innovation theory presents a valuable theoretical base for the study of MODS from a user perspective but should be enriched by further theoretical models that describe the individual's choice behaviour in more detail.

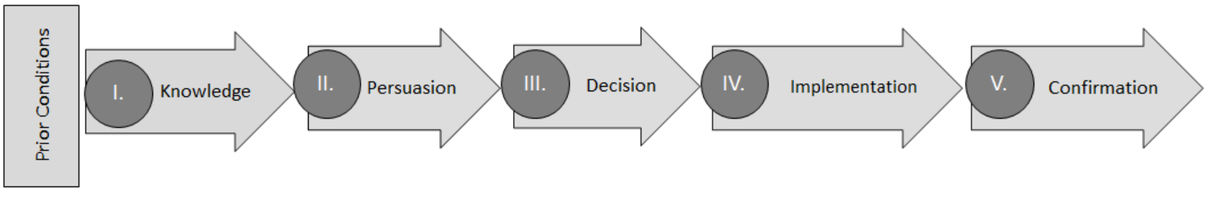

Figure 4. Five stages of the Diffusion of Innovation Model (adapted from Rogers, 2010)

Decision-making Theory

Mode choice and adoption of a transport service is based on a decision-making process. In socio-technical systems, such as traffic operations (Jipp & Ackermann, 2016), decision-making is complex due to their dynamism and uncertainty (Kurapati, 2017). Transport mode choice, especially concerning innovative and flexible transport systems, demand for models to predict decision-making under conditions of uncertainty: “Considering the inherent uncertainty in the state of the transportation system, the formulation and application of (improved) models of decision-making under conditions of uncertainty should be a field of research of high priority in travel behaviour [sic] research” (Rasouli & Timmermans, 2014a, p. 80). Closely linked to decisions under uncertainty is *Prospect Theory* that aims at describing individual’s decision-making behaviour when confronted with uncertain choices (Kahneman & Tversky, 1979). The theory is based on different theorems, most importantly, *loss aversion* that describes the phenomenon that losses loom larger than gains. Furthermore, the theory proposes that the estimation of subjective probabilities is severely biased by anchoring and people attributing greater importance to events with a low probability and insufficient importance to events with a high probability (Tversky & Kahneman, 1992). In conditions of uncertainty, travellers are expected to base their transport mode decisions more strongly on cognitive heuristics, such as anchoring effects (Kahneman, Slovic, & Tversky, 1982; Rasouli & Timmerman, 2014b).

For the case of MODS, it can be assumed, that individuals without previous experiences in using MODS face high uncertainty about the service concept. In the context of MODS, uncertainty is mainly based on a lack of predictability in the pick-up time of these services (Bansal, Liu, Daziano, & Samaranayake, 2019). Prospective users might base their decisions on more conservative and risk-aversive thinking and might also overestimate the likelihood of delays and unreliable service. Hence, the way individuals deal with travel time variability and shifts of departure or arrival time of MODS is expected to affect their willingness to use these systems. Decision-making under uncertainty in the context of travel mode choice is a research field that is far from being sufficiently explored (cf. Rasouli & Timmermans, 2014a). There have been few attempts to study route choice (de Palma & Picard, 2005; Noland & Small, 1995; Xu, Zhou, & Xu, 2011) and travel choice (Avineri & Bovy, 2008) from the angle of uncertainty of decision-making. No attempts are known to study demand-responsive transport systems or more recent developments of MODS. With travel time variability being a normal state rather than an exception for MODS (ITF, 2019), new models are needed to meet the demands of the flexible service concept of MODS. Individuals’ uncertainty about travel time, departure time, or actual time of arrival will presumably affect the appraisal and subsequently the acceptability of the service. Thus, for approaching the user perspective on MODS, the determinant of uncertainty due to the flexibility of the service concept must be incorporated into the behavioural models for describing transport mode choice.

Synoptically, it can be concluded that the above-mentioned theoretical frameworks provide some promising aspects for approaching the user perspective on MODS. Especially, technology acceptance models, attitude-based models and process models like the model of Diffusion of Innovation (Rogers, 2010) hold some promising approaches for studying MODS from the user perspective. A combination of the different models and theories might thus be an auspicious approach for this purpose. In more detail, Diffusion of Innovation theory can serve as valuable theoretical base but should be enriched by further theoretical models, like TAM (Davis, 1985), that describe the individual's choice behaviour in more detail. Furthermore, it is worth stressing that none of introduced models have been applied to the context of MODS yet. As a consequence, empirical research is needed to apply the theoretical models and, in this way, contribute to theory formation in the context of MODS.

3. State of Research and Emerging Research Gaps in the Context of the User Perspective on Flexible Public Transport

3.1 State of User Research on (Autonomous) Mobility-on-Demand Systems

Besides the current hype about MODS (Hazan, Lang, Wegscheider, & Fassenot, 2019; Van Audenhove et al., 2020), the introduction of new services is in most cases not accompanied by scientific user research (Clewlow, 2016). There is still little empirical data about how these new digitalized and flexible mobility services are used and how they may affect travel behaviour (Clewlow, 2016). Adding on this, there is a lack of empirical data about the use of MODS because these new transport systems are not yet an integral part of national mobility panels, such as *Mobility in Germany* (German: *Mobilität in Deutschland*, Kuhnimhof & Nobis, 2018).

The state of user research in the context of fixed-scheduled public transport is only transferable to MODS to a limited degree. The distinct operational concept of MODS, like the (near) door-to-door-service and the spontaneous deviation from the planned route due to the pick-up and drop-off of other passengers, limits the transferability of the existing body of literature concerning scheduled public transport to MODS. Due to the fact that the dynamic of adaptation is a system inherent characteristic of MODS, reliability and punctuality, that had proven important service characteristics for the users' appraisal of scheduled public transport systems (Redman et al., 2013, Jianrong, Wei, & Bing, 2011), are most probably attributed another meaning in the context of MODS. The same applies for travel time as a key factor for determining the public transport passengers' choice behaviour (Bourgeat, 2015; Diab, van Lierop, & El-Geneidy, 2017). Travel time will presumably be assessed differently due to its variability in MODS as a result of the spontaneous pick-up and drop-off of other passengers. All in all, the state of knowledge in the context of user requirements in conventional scheduled public transport services is hardly transferable to MODS because MODS differ from them in a large number of service attributes.

However, the state of research on the user perspective on flexible public transport might start with empirical findings regarding DRT as a preliminary form of MODS (see chapter 1.2). In the past decades, DRT systems have been mostly studied from the technical and operational side and less from the users' perspective (Finn, Ferrari, & Sassoli, 2003). In an overview study, Enoch, Potter, Parkhurst and Smith (2006) reviewed 72 international DRT projects regarding the reasons for failures and best practice examples and found that DRTs were often not planned realistically with a full understanding of the market. The authors concluded that "[…] there are a number of additional regulatory, fiscal, institutional and cultural barriers at government, local authority, operator and user levels that have not yet been comprehensively investigated […]." (Enoch et al., 2006, p. 3). Overall, an analysis of DRT systems from an operational or technical perspective only, is not sufficient to cope with the complexity of the socio-technical system of DRT and MODS.

The customers' perspective of DRT systems has been taken into account by several authors of empirical studies (Davison, Enoch, Ryley, Quddus, & Wang, 2012; Finn et al., 2003; Kahrs, 2004; Nelson & Phonphitakchai, 2012; Takeuchi, Nakamura, Okura, & Hiraishi, 2003). Nelson and Phonphitakchai (2012) conducted a household survey to examine residents' perception of a DRT system in Great Britain. They found that respondents did not know about the places served by the DRT service. Furthermore, a negative appraisal of the service was linked to a misunderstanding of the underlying service concept (Nelson & Phonphitakchai, 2012). Finn et al. (2003) presented a six-step approach for user needs analysis in the context of DRT systems. The proposed analytical approach ranged from the definition of the objectives in step 1 (*Define the objective of the User Needs Analysis)* to the dissemination of the results in step 6 *(Analyse and use the results).* By applying the six-step approach, the authors identified three main user groups for DRTs in rural areas: elderly, people with reduced mobility and home-based women without regular access to a car (Finn et al., 2003). The authors also revealed core needs of users, e.g., last-minute booking, and showed this in parallel to the operator's needs, such as maximized vehicle occupancy, which has the potential to create some form of conflict (Finn, et al., 2003). The authors concluded their analysis with the suggestion of themes for future user-centred research such as the analysis of pricing strategies for DRT (Finn, et al., 2003). Kahrs (2004) based his research on the subject of pricing strategies by modelling the willingness-to-pay (WTP) of regular bus users and non-users for different DRT systems. He found a high WTP for short waiting times (Kahrs, 2004). Accordingly, Takeuchi et al., (2003) found waiting time and travel time to affect travellers' appraisal of DRT systems in a stated preference survey. Summarizing, user-centred research regarding DRT systems can be a starting point for the study of MODS. However, the studies mentioned above addressed DRT systems in rural areas that were booked by phone calls or at a terminal several hours before the ride and mainly addressed special user groups. MODS, however, are based on an in-time booking via internet that allows on-demand rides and the target users changed to more diverse urban users (Enoch et al., 2003). To give one example, Figure 5 shows how the booking process changed from DRT to MODS. As a consequence of the considerable differences between DRT and MODS, the results of the user studies concerning DRT systems are only transferable to a limited extent.

Figure 5. Booking procedures of mobility-on-demand services in the course of time. Left: booking terminal of the demand-responsive transport R-Bus in Wunstorf, Germany in the 1970s (Schneider, 2017, republication with the permission of Airbus Corporate Heritage). Right: Booking app of the mobility-on-demand system *BerlKönig* in Leipzig, Germany in 2020 (ViaVan Technologies B.V.**,** 2020, Photo provided in the Via Press Kit by Andy Ambrosius at the ViaVan website, 2021).

Note. Translation of the descriptions of the left picture: 1. Determine the number of your destination. 2. Enter the number of your destination into the keypad. 3. Check the display of your destination number. If the number is wrong, press the correction button and select again. 4. Book by inserting the authorization card or by paying the fee in cash (DM -,20). Please do not overpay, the machine will not change. 5. Bus number and departure time are displayed and printed on your receipt as well. Please take the receipt. 6. Compare the number on the arriving bus with the number on your receipt. If it is the same, get on.

Besides research in the field of DRT systems, the analysis of pilot operations of MODS marks a starting point for research from the user perspective. Weckström et al., (2018) conducted an ex-post analysis of the Kutsuplus service that operated between 2012 and 2015 in Helsinki, Finland. They found a lack of public transport connections and low costs compared with taxis as common reasons for using the Kutsuplus service in a survey. Failures to pick up after ordering and longer travel times than anticipated were frequent reasons for stopping the use of the service (Weckström et al., 2018). The ex-post analysis of the service also showed that the residents' lack of awareness of the service and a lack of information concerning how to use the service were the main reasons not to use the service (Weckström et al., 2018). Hence, the authors concluded that "[…] marketing strategy should […] aim at education on how to use the service" (Weckström et al., 2018, p. 96). Another recent example of a scientifically accompanied pilot operation was the research project *Reallabor Schorndorf* (Gebhardt, Brost, & Steiner, 2019). The evaluation of the developed MODS showed that younger test users assessed the service better than older users (Gebhardt et al., 2019). The users' appraisal of the service was also better when they were involved in the research project as part of the participatory research approach (Gebhardt et al., 2019). The two examples from Finland and Germany showed how users and non-users of recently implemented MODS assess the service and they indicated usage barriers, such as unreliability of service and long lead times for bookings. However, the studies lack a theoretical foundation so that the interconnections between the different factors, e.g., sociodemographic characteristics, attitudes or use intention, are not sufficiently explained. Giving regard to the fact that the number of pilot operations of MODS that have a solid scientific foundation is still low, more empirically and theory-based research is needed for a systematic understanding of the various factors contributing to the user perspective of MODS.

A systematic analysis of the factors that contribute to understanding the user perspective on MODS is important for the assessment of their service quality. In this context, the perceived usefulness plays an important role for travellers' choice for or against a transportation mode (De Oña et al., 2016). Perceived usefulness has shown to affect travellers' willingness to use MODS in a case study of two rural MODS (König & Grippenkoven, 2020). However, little is known about the determinants of perceived usefulness in the context of MODS. Due to a lack of research, it remains unclear which service attributes, such as travel time, door-to-door-service or the availability of pre-booking have the most impact on users' perceived usefulness of the service.

The perceived reliability was shown to be an important service characteristic for users' assessment of service quality of public transport (Eboli & Mazzulla, 2007; Redman et al., 2013). Unreliability of public transport was the second most important factor discouraging travellers from using public transport in a study by Tyrinopoulos and Antoniou (2013). Yet, due to the fact that extra delays are system inherent characteristics of MODS, the reliability of the service may be judged differently by the users (Bansal et al., 2019). Bansal et al., (2019) conducted a discrete choice experiment to estimate the impact of waiting times due to pick-up delays on the willingness to use the service. The authors concluded that the willingness to use the service can be increased by displaying the predicted waiting time strategically to reduce unreliability.

Unreliability of service can be faced by providing real-time information (Amey, 2010). The provision of information is a basic need for transport users (Velaga, Beecroft, Nelson, Corsar, & Edwards, 2012). The service concept of MODS is likely to be accompanied by increased information needs because the flexible demand-responsive operation incorporates sudden changes from a pre-established route (König & Grippenkoven, 2020). Bansal et al., (2019) revealed in the above-mentioned experiment, that the willingness to use MODS increased by 10% when the predicted wait time was presented and thus uncertainty was reduced. The absence of a driver in autonomous MODS will presumably further contribute to increased information needs of travellers because the driver's role as a qualified respondent ceases, while the driver has a high relevance in today's public transport for responding to passenger's requests (Rohani, Wijeyesekera, & Karim, 2013). Accordingly, 83% of the respondents of a study by Fraedrich et al. (2016), who imagined the use case of AMODS, agreed slightly or strongly to the statement that they would such as to receive information on the route at any time. Hence, providing high quality information might be of uppermost importance to facilitate the adoption of (autonomous) MODS because it would lead to greater trust in the system.

Besides increasing trust in the service, providing information might also enhance users' trust in fellow passengers. This assumption is based on a study by Morales Sarriera et al. (2017) regarding ridesharing which showed that information about fellow passengers can reduce uncertainties. Another study found, that travelling with a friend of a friend or a member of the same university resulted in a higher willingness to share trips than travelling with a complete stranger (Chaube, Kavanaugh, & Perez-Quinones, 2010). This finding implies that information on fellow passengers, due to increased perceived familiarity, can improve the willingness to use ridesharing. However, similar studies have not been completed for MODS and AMODS.

Sharing rides with other passengers is one of the main characteristics of MODS that distinguishes the service from other new mobility services such as ridehailing (see chapter 1.1). Sharing of trips might imply detours for passengers. Thus, increasing passengers' willingness to share trips and accept detours is a challenging task for operators of MODS. Giving the fact that price was one of the most important factors for transport mode choice (c.f. De Oña, de Oña, Eboli, & Mazzulla, 2013; Jianrong, Wei, & Bing, 2011), MODS such as *UberPOOL* and *Lyft Line* are offered at a price of up to 50% cheaper than unshared services to provide an incentive to share trips (Alemi, 2018). As shown in Figure 6, customers of the mobility service provider *Uber* have the choice between an individual, so called *UberX* ride for $11.24 or a pooled ride for $8.50 (Uber Technologies Inc., 2020) while customers of Lyft are offered a shared ride for $4.74 and a non-pooled ride for $7.21 (Griswold, 2018). Yet, empirical findings and scientific literature could not define which discount is enough compensation to encourage travellers to share their rides with strangers and whether non-monetary incentives can have a similar effect. In addition, it is still unknown, how user characteristics such as age or gender affect these compensation demands.

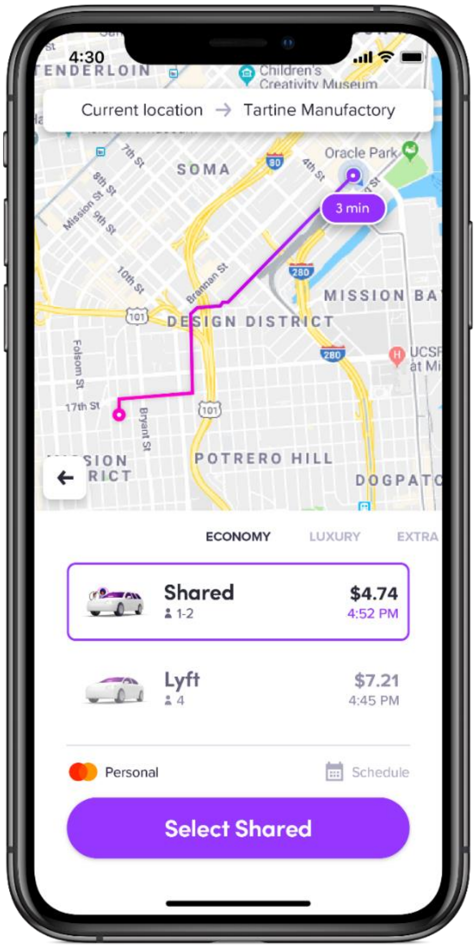

Figure 6. Booking app of the mobility-on-demand provider Lyft providing the choice between a shared and a private ride (Picture provided by the Lyft Press Kit at the Lyft website, 2021)

Besides detours, sharing rides with other passengers might come along with further inconveniences (Olsson, Maier & Friman, 2019; Wang, Winter, & Ronald, 2017). Studies recurrently report travellers' unwillingness and resistance to share rides with strangers due to the need for privacy (Lavieri & Bhat, 2018), the possibility of having a negative social interaction (Nielsen, Hovmøller, Blyth, & Sovacool, 2015; Sarriera et al., 2017), distrust in fellow passengers (Standing, Standing, & Biermann, 2019), race and social class discrimination (Moody, Middleton, & Zhao, 2019), safety and security concerns (Amirkiaee & Evangelopoulos, 2018; Nielsen et al., 2015) and fear of crowding (Tyrinopoulos & Antoniou, 2013). The negative impacts of sharing a ride with other passengers will presumably be of higher importance for autonomous MODS due to the absence of a driver acting as a person of authority. Lavieri and Bhat (2018) found that women are less likely than men to choose shared trips in AMODS. This can be very likely explained by another finding that women had stronger safety concerns in driverless busses (Shalonen, 2018). The results of Lavieri and Bhat (2018) also showed that persons with a higher income expressed a higher likelihood to share the ride in autonomous shuttles. In another study regarding AMODS, Krueger, Rashidi, and Rose (2016) found that people under the age of 30 were the most open to shared rides. In conclusion, first studies assessed the sociodemographic factors (c.f. Krueger et al., 2016; Lavieri & Bhat, 2018) and barriers that affect the willingness to share rides (c.f. Amirkiaee & Evangelopoulos, 2018; Nielsen et al., 2015; Morales Sarriera et al., 2017). However, empirical research on the psychological factors that push or encourage people to share trips in MODS and AMODS is still missing.

For AMODS, the number of empirically founded user-centred research is low, because AMODS are not yet in operation. There are, however, some studies regarding fixed-line autonomous bus shuttles, also called autonomous road transport systems (ARTS) that have already been operated in pilot studies (Eden, Nanchen, Ramseyer, & Evéquoz, 2017; Madigan et al., 2016; Nordhoff et al., 2018). The study by Madigan et al., (2016) showed that the UTAUT construct of performance expectancy had the strongest impact on the behavioural intention to use ARTS. However, the authors reported a low explanatory power of the model and proposed that the impact of other factors, such as on-board comfort and hedonistic motivation, should be further investigated. In light of the above-mentioned study by Madigan et al., (2016), the finding of an interview study by Eden et al. (2017) is interesting. The authors discovered that many interview partners felt that ARTS slowed down travel because of its low velocity (Eden et al., 2017). Thus, it can be supposed that the current level of development of ARTS affects their performance expectancy and therefore also the behavioural intention.

AMODS, that are more flexible than ARTS, are still described on a conceptual basis without a real test operation (Beiker, 2016; Fraedrich et al., 2016; Wachenfeld et al., 2016). Nonetheless, no actual experience of the technology can be assumed at the moment. However, it is important to pay attention to the user perspective on such new mobility services: “The success of such services [autonomous, shared, and electric future transport services] will crucially depend on their actual use by the population, which is in turn determined by perceptions of their usefulness, ease of use, safety, and attractiveness” (Dreßler, Grippenkoven, Jipp, Ihme, & Drewitz, 2019, p. 1). Accordingly, the expected benefits of AMODS in simulation studies by the ITF (2015a) and Spieser et al., (2014) highly depended on the user adoption rates of the service (COWI & PTV Group, 2019; ITF, 2015a; Spieser et al., 2014). However, the user needs, requirements, and usage barriers concerning AMODS have been largely neglected in previous simulation studies (e.g., COWI & PTV Group, 2019; ITF, 2015a; Spieser et al., 2014).

In the context of autonomous shuttles, users' perceived safety has shown to be an important factor for their acceptability (Grippenkoven, Fassina, König & Dreßler, 2019; Roche-Cerasi, 2019). Recent publications showed that study participants who were asked to imagine autonomous shuttles expressed worries and fears regarding the behaviour of fellow passengers (Grippenkoven et al., 2019), traffic safety (Roche-Cerasi, 2019) and security related to hacking and terrorism among other things (Roche-Cerasi, 2019). For the use case of AMODS, Fraedrich et al., (2016) showed that more than a third of the study participants perceived their safety needs as not being satisfied when imagining AMODS. According to the study, the participants expressed strong needs for transparency of the system (Fraedrich et al., 2016). Transparency has shown to positively influence trust in automated systems (Molnar et al., 2018; Salonen, 2019). Thus, studies recommend to increase system transparency and predictability through a comprehensive information provision (Hoff & Bashir, 2015; Merat, Madigan & Nordhoff, 2017). Yet, as shown before, little is known about the information needs of passengers of AMODS and the influence of the information provided on the acceptability of AMODS.

The need to include user needs in the mostly technology-driven perspective on AMODS was emphasized in recent studies (Dreßler et al., 2019; Epprecht et al., 2014; Krueger, Rashidi, & Rose, 2016). Dreßler et al., (2019) summarized challenges that are entailed by the features of flexible autonomous shuttles, such as the flexible routing and the absence of a driver. The authors also presented different methods to incorporate user needs in the system design of AMODS, such as observations, user-state monitoring and focus groups among others (Dreßler et al., 2019). A study by Krueger et al., (2016) was one of the first studies that focused on the service concept of AMODS, called shared autonomous vehicles (SAVs) by the authors. They studied the impact of different service attributes of AMODS on the user assessment of the service. They found travel time, waiting time and fare to be significant determinants of acceptability. The study further revealed that younger respondents and carsharing users are more likely to express their willingness to share trips in AMODS. Giving regard to the fact that "little is known about potential users of SAVs" (Krueger et al., 2016, p. 345), user research is now challenged to study the users and the determinants and underlying mechanisms of their acceptability of AMODS. Even though AMODS are not yet in operation, "[…] early user focus spares troubles." (Dreßler et al, 2019, p. 4). Hence, knowing the prospective users and their requirements at an early stage of development can facilitate the design and operation of user-centred AMODS in the future (Rogers, 2010).

3.2 Emerging Research Gaps and Research Questions

Several gaps emerge from reviewing the state of research of the users' perspective of MODS and AMODS. This dissertation focuses on five gaps in research: 1) to gain insight into the travellers' perception of the characteristics of the quality of service of MODS, 2) to determine users' willingness to pay for service improvements, e.g., a door-do-door service, 3) to identify and assess ways to facilitate prospective users' comprehension and knowledge of the service concept, 4) to investigate the factors that affect the willingness to share trips and the related compensation demands for detours, 5) to assess countermeasures against uncertainty and safety concerns in AMODS.

<u>Research gap 1 - To gain insight into the travellers' perception of the characteristics of the quality of service of MODS</u>

A first research gap emerges from the considerations of the travellers' perception of service quality characteristics of MODS. Regarding the new and unfamiliar service characteristics of MODS, such as the flexible routing and the waiver of fixed stops, it is still unclear how users perceive these characteristics. However, the users' assessment of the service characteristics and their perceived usefulness for fulfilling mobility needs were shown to be important determinants of use intention in technology acceptance models (Davis, 1985). However, the literature review has shown that little is known about the determinants of perceived usefulness and the assessed service quality of MODS. Thus, it remains unclear, which service attributes, such as travel time, door-to-door-service or the availability of pre-booking, have an impact on users' perceived usefulness of the service. In this context, the assessment of the reliability of the service should be emphasized, because the flexible adaptation of the route and related detours are an inherent part of the service concept of MODS (Bansal et al., 2019). In contrast, changes in the route or travel time of public transport mainly contribute to perceived unreliability of conventional public transport (Jianrong, Wei, & Bing, 2011). It is thus a pressing task for research to study the users' perception of service characteristics in more detail. Adding to this, another research need emerges on the influence of the purpose of the trip on the assessment of the service characteristics. The reason for the trip has proven to affect value of time and modal choice (Buehler, 2011; Tyrinopoulos, & Antoniou, 2013) and thus will presumably affect the relevance of the service characteristics of MODS. In conclusion, the research question RQ1 and the related sub-question RQ1.1 emerged.

RQ1: Which service characteristics of MODS affect the acceptability of the transport system?
RQ1.1: In which way does the trip purpose, e.g., business trip, influence the travellers' appraisal of the service characteristics?

Research gap 2 - To determine users' willingness to pay for service improvements

Adding to the importance to study travellers' perception of service quality characteristics, another research gap opens up regarding the users' willingness to pay for service characteristics, such as an example of this is a door-to-door-service. The literature review showed that for DRT systems, shorter waiting and travel time increased the users' willingness to pay (Kahrs, 2004; Takeuchi et al., 2003). However, for MODS, the literature review provided no insights into the willingness to pay for an improvement of the service quality of MODS in terms of a limited detour or a shorter distance to the pick-up point. In summary, research question RQ1.2 can be added as a sub-question to RQ1 regarding users' assessment of service characteristics.

> **RQ1.2**: Are prospective users willing to pay for additional service characteristics, such as a door-to-door service?

Research gap 3 - To identify and assess ways to facilitate prospective users' comprehension and knowledge of the service concept

It is still an open question, how users perceive MODS and whether they understand the service concept. The literature review had shown that a lack of knowledge about how to use the system and a misleading understanding of the operational concept have been usage barriers for DRT systems (Nelson & Phonphitakchai, 2012) and MODS (Weckström et al., 2018). Thus, the novelty barrier of MODS can put people off if they do not understand the service concept because they are unable to compare it to existing systems (Davison et al., 2012). In addition, the knowledge about a service and an understanding about how it works are preconditions for the adoption process (Rogers, 2010). Thus, the challenge is raised of how to communicate knowledge and understanding about MODS to prospective users without prior experiences with the service. Adding to this is the question of how this communication can be used to achieve a favourable attitude towards the system, which guides the adoption process according to technology adoption models (c.f. Davis, 1985; Rogers, 2010). To conclude, the research gap regarding the prospective users' conceptual comprehension and knowledge about MODS leads to the following research question RQ2.

> **RQ2**: How can knowledge about MODS be communicated to prospective users without prior hands-on experiences to increase their conceptual understanding about the service concept of MODS and at the same time be used to facilitate their willingness to use MODS?

Research gap 4 - To investigate the factors that affect the willingness to share trips and the related compensation demands for detours

The users' willingness to share trips and the related compensation demands for detours opens up a broad field for research. The ride sharing concept is especially interesting for AMODS. This assumption is based on the findings that the behaviour of other passengers was shown to be an important factor for users' perceived safety in AMODS (Grippenkoven et al., 2019) and the absence of a driver increased fears towards other passengers (Merat et al., 2017). In the context of the users' willingness to share trips in AMODS, three research questions are of particular interest. A first research question deals with the issue to what extent discounts as monetary compensations could encourage travellers to share a ride with fellow passengers and accept resulting detours. There are already MODS in operation that use different pricing schemes to attract travellers to share rides (c.f. Alemi, 2018). Yet, empirical user studies, that explore the price elasticity of users and the factors that have an impact on the willingness to pay, are missing. Thus, the research gap occurs to define a discount scheme that encourages travellers to share their trips with strangers and compensates for detours. Related to this, a second research question arises regarding the effect of travel time and detour factor on the compensation demands of users. These two service characteristics are considered of particular interest because they differ for the flexible service concept of AMODS from traditional mobility systems (ITF, 2019). The third research question deals with the impact of sociodemographic characteristics of the users on the compensation demands. To conclude, the identified research gaps result in the following research questions.

RQ3: What level of financial compensation is needed to make a shared ride more attractive than the non-shared ride in AMODS?
RQ3.1: How do travel time and detour factor affect the compensation demands of travellers?
RQ3.2: In which way do sociodemographic characteristics affect the compensation demands for shared rides in AMODS?

Research gap 5 - To assess countermeasures against uncertainty and safety concerns in AMODS

The literature review has shown that uncertainty and safety concerns played an important role in the context of MODS due to the temporal and spatial flexibility of the service (Bansal et al., 2019). Uncertainty and safety concerns of users will gain additional importance for autonomous shuttles (Grippenkoven et al., 2019; Roche-Cerasi, 2019). In this context, increasing transparency and predictability of the vehicle and its functions by providing information to the users was regarded as an important task for the user-centred design of autonomous shuttles (Hoff & Bashir, 2015; Molnar et al., 2018; Salonen). However, it remains unclear which type of information proves most effective in increasing transparency and in this way also perceived safety and acceptability of AMODS. In this context, information on other passengers can be considered of particular interest because the presence and behaviour of fellow passengers was shown to be a cause for a lack of perceived safety (Grippenkoven et al., 2019). The relevance of users' attitudes towards other passengers for the willingness to share rides was also shown for non-automated sharing systems. These attitudes were based on the possibility of having a negative social interaction (Nielsen et al., 2015; Morales Sarriera et al., 2017), distrust (Standing, Standing, & Biermann, 2019) or race and social class discrimination (Moody, Middleton, & Zhao, 2019). No attempts have been made to assess the influence of information on other passengers on the travellers' willingness to share rides in MODS and AMODS. Thus, a research gap results from the open question whether providing information about fellow travellers improves travellers' willingness to use MODS and particularly AMODS. Furthermore, it is yet to be discovered which type of personal information, such as age or gender, might be especially beneficial in improving trust in fellow passengers. This results in the research questions RQ4 and RQ4.1.

RQ4: To what extent can information about fellow passengers contribute to increase travellers' willingness to share rides in AMODS?
RQ4.1: Which information about fellow passengers proves especially relevant for increasing travellers' willingness to share rides in AMODS?

The objective of this dissertation is to fill the gap in studies of the user perspective on MODS by answering the pre-established research questions. This dissertation adapts an exploratory approach to determine MODS from a user-centred point of view and thereby enriching existing theories with new empirical findings. The main body of this dissertation is built on four studies that each approach the topic with a specific focus and research method (Figure 7). The four empirical studies are self-contained parts of this dissertation but are not independent of one another as each study is influenced by and based on the work of the other studies.

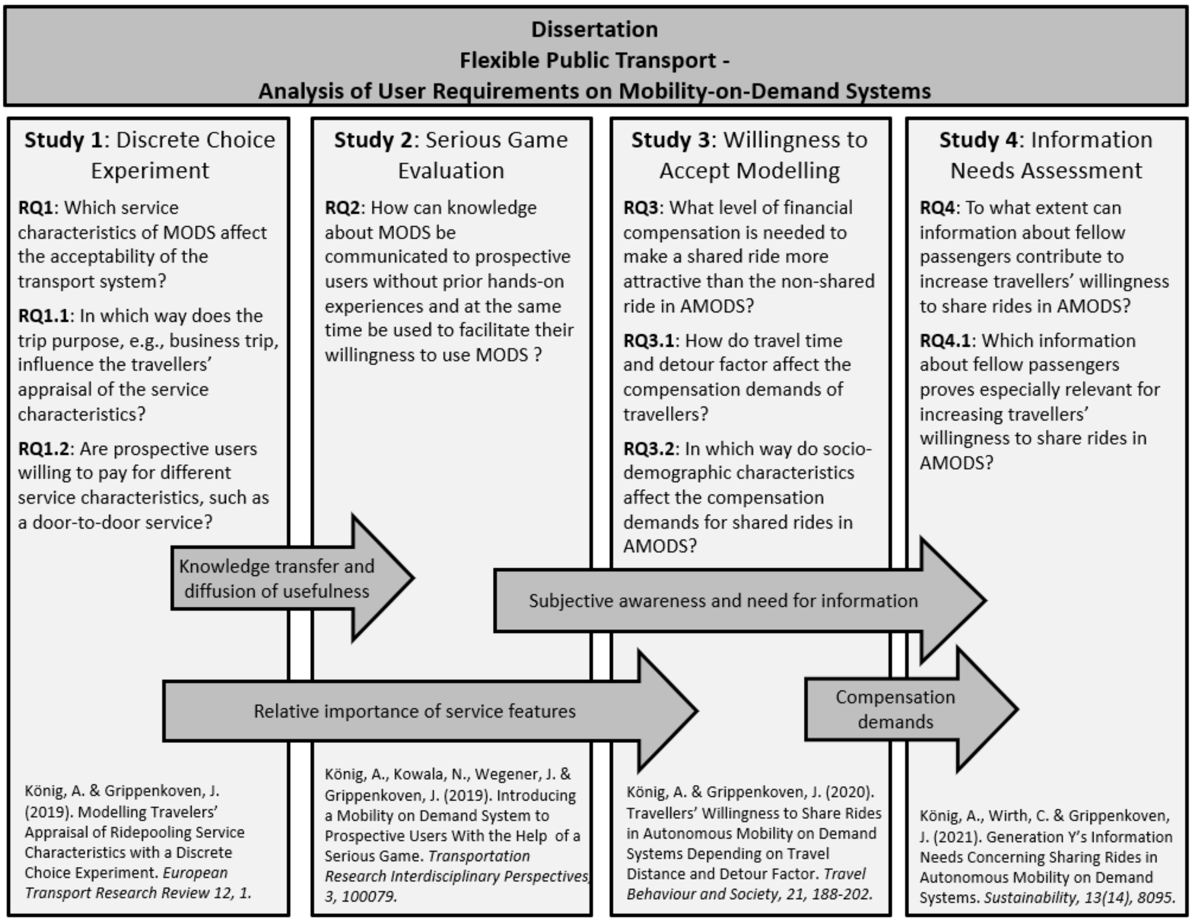

Figure 7. Outline of the cumulative dissertation based on four interrelated empirical studies.

Study 1 addressed the main research question RQ1 (*Which service characteristics of MODS affect the acceptability of the transport system?*) and the two specific research questions RQ1.1. (*In which way does the trip purpose, e.g., business trip, influence the travellers' appraisal of the service characteristics?*) and RQ1.2 (*Are prospective users willing to pay for different service characteristics such as a door-to-door service?*). A discrete choice experiment was used to answer to the research questions. Chapter 5 summarizes Study 1. The original publication with the title *Modelling travelers' appraisal of ridepooling service characteristics with a discrete choice experiment*, can be found in Attachment A. Study 1 assessed the effect of different service characteristics of MODS on the acceptability of the transport system and thereby laid the empirical foundation for the subsequent studies. Study 1 inspired Study 2 by providing insights into the factors that contribute to the perceived usefulness of the service, which was used in Study 2 to transfer knowledge about the attractive features of the service concept (see Figure 7). Study 1 also provided input for Study 3 by assessing the importance of different service features for the users' appraisal, which was used in Study 3 to determine the compensation demands of users.

Study 2 built upon the findings of study 1 by imparting knowledge about the service concept of MODS and the service characteristics to prospective users. Study 2 aimed at answering the research question RQ2 (*How can knowledge about MODS be communicated to prospective users without prior hands-on experiences to increase their conceptual understanding about the service concept of MODS and at the same time be used to facilitate their willingness to use MODS?*). Adding on the other research studies that are devoted to the individual's appraisal of service characteristics of MODS, chapter 6 addresses the question how the new service can be introduced to the prospective users. The chapter thus complements the other research studies summarised in this dissertation by providing insights into the early phases of the adoption process of MODS. Study 2 presented an experimental study to compare the effects of two methods of providing knowledge, attitudes and willingness to use MODS. In more detail, a developed learning game, so called *serious game*, was evaluated. The study is summarized in chapter 6 and attached as publication under the title *Introducing a Mobility on Demand System to Prospective Users with the Help of a Serious Game* in Attachment B.

Study 3 addressed the ride sharing concept and the related detours as system inherent characteristics of MODS. Study 3 focussed on AMODS because the ride sharing concept was shown to be of particular relevance for driverless MODS in the literature review. Study 3 used the methodological approach of willingness to accept modelling for addressing the research question RQ3 (*What level of financial compensation is needed to make a shared ride more attractive than the non-shared ride in AMODS?*) and the related sub-questions RQ3.1 (*How do travel time and detour factor affect the compensation demands of travellers?*) and RQ3.2 (*In which way do sociodemographic characteristics affect the compensation demands for shared rides in AMODS?*). Study 3 complemented Study 1 and Study 2 by methods from economics to assess the willingness to accept and to determine the compensation demands of travellers for sharing a ride with fellow passengers. The study thereby used the findings of Study 1 concerning the importance of service characteristics for travellers' choice behaviour. Study 3 is summarised in chapter 7. The underlying publication of Study 3 can be found in Attachment C under the title *Travellers' Willingness to Share Rides in Autonomous Mobility on Demand Systems Depending on Travel Distance and Detour Factor*.

Study 4 built upon the findings of Study 3 and the assessment of the compensation demands by adding new insights about the effect of providing information on individuals' compensation demands for sharing rides. Study 4 thereby is also based on the findings of Study 1 and Study 2 regarding the impact of information provision on travellers' willingness to use MODS. More specifically, Study 4 aimed at answering the research question RQ4 (*To what extent can information provided about fellow passengers contribute to increase travellers' willingness to share rides in AMODS?*) and the related sub-question RQ4.1 (*Which information about fellow passengers proves especially relevant for increasing travellers' willingness to* *share rides in MODS?*). Study 4 is summarized in Chapter 8. and attached in full under the title: *Generation Y's Information Needs Concerning Sharing Rides in Autonomous Mobility on Demand Systems* (Attachment D).

5. Study 1 - Modelling Travellers' Appraisal of Ridepooling Service Characteristics with a Discrete Choice Experiment

This chapter presents a research paper that was published as König, A., & Grippenkoven, J. (2019). Modelling travellers' appraisal of ridepooling service characteristics with a discrete choice experiment. *European Transport Research Review* 12**,** 1. https://doi.org/10.1186/s12544-019-0391-3 (see attachment A).

The chapter lays the foundation for the following chapters and research papers by addressing these research questions:

- RQ1: Which service characteristics of MODS affect the acceptability of the transport system? Which service characteristics of MODS affect travellers' appraisal of the system?
- RQ1.1: In which way does the trip purpose, e.g., business trip, influence the travellers' appraisal of the service characteristics?
- RQ1.2: Are prospective users willing to pay for additional service characteristics, such as a door-to-door service?

5.1 Introduction

In the early years of the twenty-first century, a variety of new mobility services have emerged within the range between conventional public transport and individual transport, which are enabled by the rapid growth of information technology and digitalisation (Jain, Ronald, Thompson, & Winter, 2017). MODS use matching algorithms to pool the routes of passengers that are heading in the same direction and providing an on-demand transport service without fixed schedules (Shaheen & Cohen, 2018). Based on the promise to provide a more user-centred and on-demand service than public transport a large number of mobility-on-demand services have been launched recently, such as *MOIA* in Hamburg (Gilibert, Rogas, & Rodriguez-Donaire, 2017), *Kutsuplus* in Helsinki (Jokinen, Sihvola, & Mladenovic, 2019) or *Berlkönig* in Berlin (Viergutz & Brinkmann, 2018; Ullrich, 2019). Yet, the rapid launches of these new services had not been accompanied by empirical research, and insights into the users' preferences and appraisal of these innovative mobility services are still missing (Tsafarakis et al., 2019). Thus, there is little information about how these new digitalized and flexible mobility services are used and how they may affect travel behaviour (Clewlow, 2016). Existing empirical knowledge about the user perspective on public transport systems cannot be simply transferred to new MODS because the service concept is in large part very different from scheduled public transport. MODS waive fixed service elements, such as a schedule, in favour of flexible demand-responsive service elements. Thus, it can be expected that users perceive the service in a different way than conventional public bus service. Service quality characteristics that have proven to affect users' perception of the service, such as travel time (Beirão & Cabral, 2007) and frequency (Hansson, Pettersson, Svensson, & Wretstrand, 2019), must be re-assessed in the light of a demand-responsive service concept. The article builds upon this research gap by studying the travellers' appraisal of MODS. To close this research gap, the study addressed RQ1, RQ1.1 and RQ1.2.

5.2 Method

The study was based on a discrete choice experiment (DCE) to model travellers' preferences concerning the service of MODS. The DCE is a method of Stated Preferences (SP) and represents a widely accepted method to investigate potential users' preferences of hypothetical services or products which otherwise could not be judged by people who did not used the service before and thus cannot adequately imagine it (Bellizzi, dell'Olio, Eboli, & Mazzulla, 2020; Földes & Csiszár, 2018). SP methods were used before in the context of new mobility services (Cao & Wang, 2016; Földes & Csiszár, 2018; Frei, Hyland, & Mahmassani, 2017; Krueger, Rashidi & Rose, 2016). DCE are especially useful for understanding the trade-off travellers may be willing to make between different attributes (Louviere, Flynn, & Carson, 2010). Because literature emphasized the importance of a comprehensive process for the definition of attributes of a DCE (Kløjgaard, Bech, & Søgaard, 2012), a literature review was conducted to determine the service characteristics that have proven to affect travellers' appraisal in the context of scheduled bus transport (see table 1 in attachment A). In the online survey, the decision-maker was confronted with choice sets that consist of different alternatives, characterized by attributes and their varying levels. The study used the six attributes *time of booking, walking distance, shift of departure, travel time, information provision* and *fare*, that were combined based on a fractional factorial design according (Aizaki, Nakatani, & Sato, 2015) to a subset of 24 choice sets. Each choice set consisted of two alternatives and a *none-of-these* option. The DCE was based on two usage scenarios (between-subjects-design): 1) a *shopping trip* to the city centre on a weekday afternoon with the purpose of the trip to buy a gift card and 2) a *doctor's appointment* on a weekday afternoon. Data from 410 individuals were analysed with a Mixed Multinominal Logit (MMNL, McFadden & Train, 2000), which is consistent with Random Utility Theory (RUT, Louviere, Flynn & Carson, 2010). See attachment A for more details about the data analysis procedure.

5.3 Results

The MMNL provided regression coefficients for the six service attributes that reflect the attributes' contributions to the overall utility of the system (Hair, Black, Babin, & Anderson, 2010). All coefficients significantly contributed to the overall utility. To be specific, respondents proved to be attentive to the fare and very sensitive to an increase of the walking distance to the pick-up point. Furthermore, shifts of the point of departure, a prolongation of travel time and higher lead time for bookings decreased the perceived utility of the service. The attribute information in contrast revealed a conducive impact on the respondents' appraisal of the ridepooling systems.

The purpose of the trip had a considerable impact on the choice behaviour of the respondents. To be more concrete, respondents that were confronted with the scenario of a doctor`s appointment showed to be more attentive to the attributes travel time and shift of departure than respondents who were requested to imagine a shopping trip. Furthermore, respondents that envisioned a doctor's appointment as the purpose of the trip were more sensitive to an increase in walking distance to the pick-up point. No effect of the purpose of the trip on the attributes fare, booking time and information was proven.

In addition, the willingness to pay (WTP) for each attribute was calculated (Sillano & de Dios Ortúzar, 2005). The respondents' willingness to pay for an improvement in the quality of service differed depending on the trip purpose in a way that the respondents who imagined the doctor's appointment were willing to pay an extra amount for reducing the walking distance to the pick-up point and the travel time compared to the shopping trip. Independent of the purpose of the trip, respondents revealed a high willingness to pay for a smaller shift of the point of departure.

5.4 Discussion

The study was based on the research need to study user requirements for emerging MODS because findings concerning scheduled public transport are limited in their transferability to these new demand-responsive services. By using a Discrete Choice Experiment, the study contributed to gaining insights into the prospective users' appraisal of service features and usefulness-determining aspects of MODS. To summarize, Study 1 presented an empirical approach to address the research question RQ1 (*Which service characteristics of MODS affect the acceptability of the transport system*?). A discrete choice experiment revealed that the six service characteristics, that were identified with the help of a literature review and a focus group, affected the choice behaviour of the study participants. The study further provided insights with regard to research questions RQ1.1 and RQ1.2 concerning the relevance of the purpose of the trip and the willingness to pay for service improvements, such as a shorter walking distance to the pick-up point.

To conclude, the model revealed that low fares, short walking distances to the pick-up point, short travel times, a timely possibility of booking, small shifts of departure and the presentation of information played a major role in the perceived utility of the services. In more detail, the attribute fare had a strong impact on the respondents' choices, confirming findings in the field of ridesharing (Malodia & Singla, 2016). Furthermore, the analysis underlined the importance of the service characteristic walking distance, underlying the relevance of a door-to-door-service and confirming the research concerning carpooling (Wilkowska, Farrokhikhiavi, Ziefle, & Vallée, 2014). The findings further imply a high sensitivity to the issue of travel time as shown by a high perceived utility of slight travel time prolongations. The service aspect of travel time was especially relevant when envisioning a doctor's appointment with a specific time. In the context of additional travel time the flexibility of the departure time should also be discussed because respondents reacted sensitively to shifts of departure time. The study further emphasized the importance of providing information for the respondents' appraisal of the service quality.

Study 1 revealed that the transferability of previous findings concerning the user perspective on public transport to MODS is limited. The flexibility and dynamics of the service concept are system inherent features of MODS and service characteristics that have proven to affect users' appraisal of the service. Reliability and frequency of service receive another meaning in the light of the demand-responsive service of MODS. Yet, the analysis revealed that the respondents are sceptical about the flexibility of the service features, such as a longer travel time due to picking-up of fellow travellers. However, the timely and spatial flexibility is an inherent system characteristic of mobility-on-demand schemes and a shift of departure or a prolongation of travel time are not exceptional but are the usual state of such a system. The study thus suggests the importance of comprehensive explanations and knowledge about the service concept of MODS to be given to the prospective users. Furthermore, the relevance of real-time information provision for the travellers' appraisal of the service quality is underlined. Based on the findings, several recommendations for the design and operation of MODS can be derived. These aim at giving guidance for the creation of a user-centred public transport system that meets the requirements of the prospective passengers (see Attachment A). The results marked a starting point for further research in the context of user requirements on MODS and laid a foundation for the following study 2 by determining which service characteristics of MODS are important for users' appraisal of the service.

6. Study 2 – Introducing a Mobility on demand System to Prospective Users with the Help of a Serious Game

This chapter presents a research paper that was published as:
König, A., Kowala, N., Wegener, J., & Grippenkoven, J. (2019). Introducing a Mobility on Demand System to Prospective Users with the Help of a Serious Game. *Transportation Research Interdisciplinary Perspectives, 3, 100079*. https://doi.org/10.1016/j.trip.2019.100079 (see attachment B).

The chapter addresses the research question:

- RQ2: How can knowledge about MODS be communicated to prospective users without prior hands-on experiences to increase their conceptual understanding about the service concept of MODS and at the same time be used to facilitate their willingness to use MODS?

6.1 Introduction

The big difference between MODS and a scheduled public transport is that the first provides a demand-responsive transport service which waives fixed schedules and routes in favour of flexible routing. It can be reasonably assumed that the novelty of the service concept of MODS represents a challenge for prospective users' understanding of the operation concept and service model (see chapter 3.1.). The evaluation of the MODS *Kutsuplus* in Helsinki had shown that the residents lack information on how to use the service (Weckström et al., 2018). This lack of awareness about the service was the main reason not to use it (Weckström et al., 2018). It can be thus concluded, that missing or insufficient information are relevant barriers to the adoption of MODS. König, Wegener, Pelz, and Grippenkoven (2017) worked out two more major challenges for the user-centred introduction of MODS: the challenge of favourable appraisal and the challenge of acceptance that refers to the active willingness to use the service (Ambrosino et al., 2003). To address the three challenges, traditional means of raising awareness, facilitating understanding and contributing to a favourable appraisal are limited in their power to create an immersive environment to envision new mobility concepts and to actively engage prospective users in experiencing the service. New interactive and digitally based immersive research settings might have shown to provide a promising way to bridge the gap between dissemination and adoption (Distler, Lallemand, & Bellet, 2018). As one immersive approach, a serious game was used in this study to introduce the service concept of MODS to prospective users.

So called *serious games* are characterized by "a thought-out educational purpose and are not intended to be played primarily for amusement" (Abt, 1970, p. 9). Several empirical studies confirmed the effectiveness of game-based learning (Connolly et al. 2012, Sitzmann, 2011; Tennyson and Jorczak, 2008; Wouters et al., 2013) due to different game mechanisms that ensure learners attention, provide continuous and immediate feedback and an appropriate level of challenge (Boyle et al., 2011; Shute, 2011). For transportation research, games are a promising approach to depict the complexity and dynamics of transport (De Bruijn and Herder, 2009; Mayer et al., 2010) and thus have been used in different transportation research domains (Duffhues et al., 2014; Freese et al., 2016; Klemke et al., 2015; Wittowsky, 2009; Yusoff, 2010).

The study used a game-based learning approach to introduce MODS to prospective users and to answer the research question. For this purpose, the serious game *B.u.S.* (German: Bürger unterrichten durch Spiele, engl.: Teaching citizens through games) was created and implemented. The game's effectiveness for increasing players' knowledge about MODS, for improving their attitude towards the systems and increasing their willingness to use the systems was assessed in an experimental evaluation study. For this reason, a research model based on the Diffusion of Innovation Theory (Rogers, 2003) and the Technology Acceptance Model (Davis, 1989) was developed (see Attachment B for a detailed description). The aim of the serious game was to enhance knowledge of players according to the three knowledge types of Rogers (2003): awareness-knowledge, how-to-knowledge and principles-knowledge.

6.2 Methods

To meet the challenges related to the introduction of new mobility services (see Section 2.1) the serious game *B.u.S.* was designed as a single-player role game that puts the players in the position of a public traffic planner to experience the new transport system from another perspective than the user perspective (König et al., 2017). In *B.u.S.* the player's tasks are to plan and operate a mobility-on-demand system by routing the vehicle according to the mobility needs of the residents of a virtual city. By facing the challenge to plan the service in a user-centred, and also environmentally-friendly and economically efficient way, the players are expected to understand the logic and complexity of operational planning. Furthermore, a scheduled bus is introduced in a higher level of *B.u.S.* to demonstrate the differences between the service concepts and to demonstrate the benefits of flexible routing of MODS. The experimental game approach encourages the player to actively take part in the new system with all its functions and constraints.

The evaluation study was conducted in a high school in Luckenwalde, a small town that is located in a rural area of eastern Germany and has a MODS, called Rufbus that has been operating since 2010. The study's participants were pupils of 10th to 12th grade (N = 71). The mean age of the sample was 16.75 years (SD = 1.07 years). The study design entails between-subjects design with a control group that was instructed to perform online research concerning MODS. The evaluation study was based on three questionnaires: 1) a pre-test, 2) a post-test and 3) a second post-test, four weeks after the game session. The experimental group played the serious game for 15 minutes on smartphones or tablet computers and did a 5-minutes written reflection on the game and what they had learned, as a debriefing phase (Crookall, 2010). The control group was encouraged to inform themselves about mobility on demand systems with the help of online research with tablet computers or smartphones for 20 minutes. The online research was chosen as a comparative measure because seeking online information is a very common way for adolescents to obtain information (Micheli, 2015).

6.3 Results

The analysis showed that the interventions had a positive effect on the increase of knowledge about the mobility-on-demand concept. The game had a significant positive effect on the retention rate of the differences between the two bus concepts four weeks after the intervention compared to the control group. Contrary to expectations, the online research proved most beneficial in helping acquire the knowledge on how the operational system of MODS work.

Regarding the participants' assessment of the usefulness of MODS, a marginally significant higher value was found for the experimental group. When looking at the usefulness items separately, a significant effect of the serious game was shown concerning the usefulness assessment for transport agencies. The game was also linked to a better assessment of personal mobility compared to the control group. Yet, it was shown that the control group had a better assessment of the benefits for the environment.

A significant main effect of the intervention on the perceived likelihood to use MODS within the next four weeks was shown for both groups after the intervention. Yet, no effect of the serious game on the willingness to use the transport system was revealed.

In the post-test four weeks after the intervention, only one participant stated to have used the mobility-on-demand system in the meantime. The person concerned had used the local MODS before and belonged to the experimental group. Thus, there was no effect of the serious game on the actual use of the system.

6.4. Discussion

The research article 2 (attachment 2) assessed a serious game's effectiveness as an instrument to introduce a new transport system to the prospective users, thus addressing the research question RQ2. More specifically, the study aimed at approaching the challenge of facilitating users` conceptual comprehension and knowledge about the service concept and thereby increasing the willingness to use it.

The study found clear indications for beneficial effects of the serious game to contribute to individuals' conceptual comprehension and understanding. The study further revealed an improvement in the participants' perceived usefulness of the mobility-on-demand system after playing the game, which proved to be an important determinant of a favourable appraisal of demand-responsive systems (König & Grippenkoven, in review). The study thus addressed the research goal to raise awareness about the usefulness of the service. Yet, no effects on the willingness to use and the actual usage behaviour were found. The game evaluation study thus proved the games effectiveness for the first phases (knowledge phase and persuasion phase) of the proposed research model based on the Diffusion of Innovation Model (Rogers, 2010) but not for the later phases (*decision phase* and *implementation phase*). The findings are in line with a considerable number of studies that failed to prove a positive effect of serious games on actual behaviour (Cowley & Bateman, 2017; DeSmet et al., 2014, Majumdar et al., 2013).

To conclude, the approach using the game B.u.S. emerged as a tool that is not less effective for facilitating the adoption of MODS than online research. Instead, the serious game proved to be more beneficial in facilitating long-term retention of knowledge about the service concept and a higher perceived usefulness. The game evaluation study thus addresses the research question RQ2 (How can knowledge about MODS be communicated to prospective users without prior hands-on experiences to increase their conceptual understanding about the service concept of MODS and at the same time be used to facilitate their willingness to use MODS?). It can be concluded that the serious game presents in some ways a promising approach to impart knowledge about the service concept of MODS to prospective users and improves their perception of usefulness of the service. Conclusively, for using a serious game as a research instrument in the transportation domain, several challenges have to be considered in the design, development and use of the serious game, as reflected by Freese, Lukosch, Wegener, and König (2020) based on the presented game and two other case studies.

7. Study 3 - Travellers' Willingness to Share Rides in Autonomous MODS Depending on Travel Distance and Detour Factor

The following research study was published as:

König, A. & Grippenkoven, J. (2020). Travelers' Willingness to Share Rides in Autonomous Mobility on Demand Systems Depending on Travel Distance and Detour Factor. *Travel Behaviour and Society, 21*, 188-202. https://doi.org/10.1016/j.tbs.2020.06.010 (see attachment C).

The following chapter is dedicated to the research questions:

- RQ3: What level of financial compensation is needed to make a shared ride more attractive than the non-shared ride in AMODS?
- RQ3.1: How do travel time and detour factor affect the compensation demands of travellers?
- RQ3.2: In which way do socio-demographic characteristics affect the compensation demands for shared rides in AMODS?

7.1. Introduction

A high occupancy rate of transport systems is an essential requirement for sustainable mobility systems because privately used ridehailing systems can cause an increase in traffic (San Francisco County Transportation Authority, 2018; Tirachini and Gomez-Lobo, 2017). Therefore, ridesharing is seen as the key to autonomous transport (Bösch, Becker, Becker, & Axhausen, 2017; COWI & PTV, 2019; Tirachini & Gomez-Lobo, 2017; World Economic Forum, 2018). There is a branch of research studying the psychological determinants of ridesharing (Gilibert, Ribas, & Rodriguez-Donaire, 2017; Zhang, He, Xioa, & Ma, 2016). However, there are few empirical findings concerning the user perspective on ridesharing in AMODS (Lavieri & Bhat, 2018; Krueger et al., 2016). These studies have shown that men (Lavieri & Bhat, 2018) and people under the age of 30 were the most likely to choose shared trips in AMODS (Krueger et al., 2016). Nonetheless, empirical research on the psychological factors that push or encourage people to share trips in MODS and AMODS is still missing. Giving regard to the fact that ridesharing represents a system-inherent characteristic of AMODS, research is challenged to study the factors that facilitate the users' willingness to share rides in AMODS.

Taking into consideration the findings of Study 1, which showed that price was an important service characteristic for travellers' assessment of MODS, monetary incentives might be a powerful measure to encourage travellers to share rides in autonomous MODS. A further research need emerges concerning the question, how travel time and detour, as important service characteristics of MODS (see Study 1), affect travellers' willingness to share rides in AMODS.

7.2 Material and Methods

The study adopts the notion of willingness to accept (WTA), as a measure for the individual's compensation demands for a shared ride. A Stated Preference (SP) experiment was conducted to examine the WTA. Two independent variables were considered in the study: travel time and detour factor. The participants of the online survey (*N* = 151) were introduced to 15 choice tasks that consisted of a non-shared and a shared ride. They were asked to specify the maximum value they were willing to pay for the shared ride to assess the WTA. They also had the possibility to choose none of the two alternatives (refusal rate).

7.3. Results

The study was analysed according to two dependent variables: 1) refusal rate (share of rejected shared rides) and 2) WTA.

The study revealed a high acceptability of shared rides in autonomous MODS as reflected by a low refusal rate. It was further shown that the refusal rate was higher if the route entails higher detours and a longer travel time compared to smaller detours and shorter travel times. Moreover, an effect of sociodemographic characteristics of the participants was noticeable: women and individuals under the age of 33 tend to refuse the shared rides less often compared to men and older people.

Concerning the WTA as a measure for the compensation demands of travellers to accept shared rides, a regression analysis revealed that respondents required higher discounts, expressed by a lower WTA, when travel time and detour increase. Regarding the effect of individuals' sociodemographic characteristics, lower income and young age were linked to a higher WTA. In contrast to the findings regarding the refusal rate, male gender was attributed to a higher WTA. A cumulative distribution function of the WTA was used to describe the cost sensitivity of the respondents. As shown here, a critical mass of 90% of respondents would favour a 10-minutes shared ride instead of a non-shared ride if the price for the shared ride is 50% of the non-shared ride's price. The study also displayed, that the compensation demands varied strongly, depending on the detour factor. Thus, the WTA of 90% of the respondent decreased to 46.7% if the detour factor is 1.2 and further decreased to 37.5%, 32.5% and 26.7% for detour factors of 1.3, 1.4 and 1.5 respectively. Regarding the model fit, the analysis showed that the model explained about 32% of variance.

7.4. Discussion

Study 3 was motivated by the novelty of AMODS. The ridesharing concept of these transport systems was of particular interest for this study. Because Study 1 (chapter 4) had shown that the additional travel time due to the pick-up and drop-off of fellow travellers was a relevant factor for the acceptability of MODS, Study 3 addressed the travellers' willingness to share rides in more detail. Based on the results of the regression analysis, a function to describe the compensation demands of travellers for shared rides in autonomous MODS was derived. The function underlined the relevance of the travel time and detour factor on the compensation demands of shared rides, thus confirming the findings of Study 1 (chapter 4). By examining the travellers' willingness to share rides in AMODS the study provided first insights into the research question RQ3, RQ3.1 and RQ3.2. Based on the findings, it can be concluded that the level of discount for a shared ride depended on the trip characteristics as well as individuals' socio-demographic characteristics. According to the findings, the pricing scheme of autonomous MODS should be based on the travel time and the additional travel time resulting from the detour and not on a fixed discount scheme. Inter-individual findings also indicate that socio-demographic characteristics of individuals affect their compensation demands for shared rides. Apparently, the age of the respondents influenced the amount of discount needed for selecting the shared alternative in a way that younger travellers demand fewer discounts. The results thus confirmed the findings of Fraedrich et al., (2016) who revealed greater openness towards autonomous mobility-on-demand concepts for younger individuals. Furthermore, as recent studies already suggested (Lavieri & Bhat, 2018; Shalonen, 2018; Morales Sarriera et al., 2017), female gender was linked to higher compensation demands.

To conclude, the study findings implied that the willingness to share rides in AMODS depends on trip characteristics (travel time and detour factor) as well as personal characteristics (age, gender and income). A service concept that takes these differences into account by offering the possibility of personalization (e.g., determining maximum accepted detour) is thus expected to experience greater acceptability. Based on the findings, a travel time and detour dependent pricing system is expected to be more attractive to travellers than a fixed discount scheme as used by MyTaxiMatch (Betzholz, 2017).

The study raised further research questions. Above all, it should be noted that the model explained a relatively low share of variance, thus indicating that other factors play an important role for predicting individual's willingness to share rides in autonomous MODS. Furthermore, it could be interesting to study the effects of the presentation of information concerning the proposed rides (e.g., concerning the detour factor and changes in arrival time) on the traveller's assessment of the shared ride option and the choice behaviour. Adding to this, the question arises whether providing information about the service could increase transparency and reliability of the service. In this context it is also of interest to study the effects of the shared information about fellow travellers on the willingness to share rides in autonomous MODS because feelings of insecurity are important concerns of travellers, when imagining a ride in an autonomous public transport system (Shalonen, 2018). Furthermore, the low percentage of variance extracted by the model indicates the need for taking further predictors of users' acceptability of sharing rides in AMODS into account.

8. Study 4 - Generation Y's Information Needs Concerning Sharing Rides in Autonomous MODS

The following chapter comprises a research paper that is under review:

König, A.; Wirth, C., & Grippenkoven, J. (2021). Generation Y's Information Needs Concerning Sharing Rides in Autonomous Mobility on Demand Systems. *Sustainability, 13*(14), 8095. https://doi.org/10.3390/su13148095

Study 4 aimed at answering the following research questions:

- RQ4: To what extent can information provided about fellow passengers contribute to increase travellers' willingness to share rides in AMODS?
- RQ4.1: Which information about fellow passengers proves especially relevant for increasing travellers' willingness to share rides in MODS?

8.1 Introduction

The flexibility and demand-responsiveness of the service concept of AMODS is expected to be linked to higher information needs of travellers (see section 3.2). In this context, information concerning the state of the vehicle functions, the service status (e.g., route changes) and the fellow passengers becomes presumably more important. Dreßler et al., (2019) revealed fears related to other passengers to be a strong aversive factor in the context of shared autonomous transport systems, next to uncertainty related to a system's lack of transparency and the system's safety from a technical point of view. Accordingly, literature outlined several barriers for sharing rides in autonomous vehicles, such as the possibility of having a negative social interaction, distrust or safety and security concerns (Amirkiaee & Evangelopoulos, 2018; Lavieri & Bhat, 2018; Morales Sarriera et al., 2017; Nielsen et al., 2015). Some studies also reported feelings of prejudice towards other passengers and discrimination linked to the race or socio-economic class of fellow travellers in ridesharing systems (Carol, Eich, Keller, Steiner, & Storz, 2019; Morales Sarriera et al., 2017). Because system transparency was an important influencing factor for users' trust in automated systems (Molnar et al., 2018; Salonen, 2018; Strauch et al., 2019), comprehensive information is expected to be a key factor for the user acceptance of autonomous MODS. Thus, it can be argued that providing information about fellow passengers can possibly enhance trust and reduce feelings of uncertainty while sharing rides by increasing transparency.

Study 4 aimed at answering the question, whether providing information about fellow travellers affects the willingness to share rides in MODS. And if so, which information proves especially effective. Study 4 thereby builds upon the findings of Study 3 which have revealed the effect of travel time and detour factor on the compensation demands of study participants for sharing a ride in autonomous MODS (see chapter 6.3). Based on a literature review (see Attachment 4) several potential determinants of the willingness to share rides were identified. More specifically, the present study examined the effect of four potential determinants on the willingness to share rides with fellow travellers: 1) travel time, 2) degree of vehicle automation, 3) quality of information on fellow passengers and 4) gender of the fellow passenger. Therefore Study 4 focussed on a specific potential user group - *Generation Y*, so called millennials, who were born between 1981 and 1999 (Capasso da Silva et al., 2019). Based on related literature concerning the sharing economy (Bolton et al., 2013; Möhlmann, 2015) and the findings of Study 3, this specific cohort is expected to be especially likely to adopt AMODS.

8.2 Materials and Methods

To answer the research questions an open-ended contingent valuation method (CV) was used as stated preference method (Boyle, 2017). The applied study design was similar to the method of Study 3 (see chapter 6.2). To determine, the effects of providing information on the dependent variable WTA, five levels of information on fellow passengers were examined: 1) no information (bus stop sign), 2) name, 3) picture, 4) rating and 5) full profile information (name, picture and rating). Further independent variables were respondent's gender, information on the gender of the fellow traveller, travel time and automation level (with driver vs. driverless). The participants were asked to respond to 16 choice tasks.

Only survey respondents assigned to the Generation Y (aged between 18 and 39 years) were included (N = 154). The sample was characterized by a mean age of 26.5 years (SD = 4.4 years) and included slightly more women (n = 95, 61.7%) than men (n = 57, 37.0%, rest missing).

8.3 Results

First, the rate of respondents, that rejected the shared rides (refusal rate), was analysed. The overall refusal rate across all levels of information provision was 2.7% (SD = 1.6%) and thus comparable to the findings of Study 3. The mean refusal rate differed depending on the quality of information given about the fellow passengers. Accordingly, refusal rate was the highest with 7.1% (SD = 0.26%) when only a male name was presented for the long ride scenario. A Generalized Linear Mixed Model (GLMM) proved the effect of travel time, level of information about fellow travellers and gender information on the refusal rate.

Regarding the WTA, a first descriptive analysis found that the WTA was lowest for the scenario of a 25-minute ride without any information on the fellow traveller (bus stop sign, M = 67.12%, SD = 25.63%) and the highest for the short ride with full profile information (M = 76.14%, SD = 17.20%). A mixed-effects model proved a highly significant effect of travel time on WTA and a marginally significant effect of vehicle automation and information on the gender of the fellow passenger. Quality of information revealed to be a significant predictor only for the dummy-coded variable concerning full profile information. The regression analysis also showed that the WTA significantly increased when full profile information was presented compared to the baseline condition bus stop sign. In contrast, the presentation of only a name revealed a significant negative effect on the WTA. The analysis revealed an interaction between gender and the presented gender information on the WTA (see Attachment D). Furthermore, the lowest discount to attract 90% of the respondents, was needed for the scenario of a full female profile (see Attachment D). A cumulative distribution of the WTA was used to assess the respondents' cost sensitivity according to the independent variables.

8.4 Discussion

Study 4 assessed the influence of information on fellow passengers on the travellers' acceptability of sharing rides in autonomous MODS for a Generation Y sample. The study thereby enriched the findings of Study 3 regarding the compensation demands for sharing rides in AMODS.

The analysis revealed a beneficial effect of detailed information about fellow travellers that comprise picture, name and a rating for reducing the compensation demands of travellers. It was shown that the provision of only a name resulted in higher compensation demands. The effect was even greater when a male name was provided. The results are in line with the findings of Carol et al., (2019) who found a lower willingness to share a trip with male than female passengers for a ridesharing system. To summarize, the findings of Study 4 implied that using a profile name without further personal information is not recommended for future AMODS. The study found clear indications for beneficial effects of the provision of information about fellow travellers on the willingness to share rides in autonomous MODS. Study 4 provided insights into the research questions RQ4 and RQ4.1 concerning the effect of providing information on fellow passengers on the compensation demands for shared trips. As shown here, the presentation of full profile information (name, picture and rating) was especially effective to lower compensation demands for ridesharing. As shown in the analysis, the presentation of purely name information reduced the willingness to share rides and so is not recommended. Presenting a rating of the fellow passenger proved beneficial for reducing the discount needed to attract a critical mass of travellers to share rides.

The study provides first empirical insights into the importance of information on fellow travellers in future autonomous MODS. However, further studies are needed to provide a deeper look at these preliminary findings and to validate the results in more naturalistic settings. Given regard to the fact that the findings point to clear differences in the willingness to share AMODS depending on the gender of fellow passengers, further research is needed to study the effects of further information on fellow passengers, such as age or ethnic background.

9. Discussion

This dissertation comprises four research studies that investigated the user perspective of MODS in different ways. In the following, the results of the four research studies are summarized and linked to each other (chapter 9.1). Subsequently, the results of the four studies are embedded in the state of research and theoretical models (chapter 9.2). Finally, the chapter concludes with a reflection of restrictions and limitations of the methodology (chapter 9.3).

9.1 Summary and Assessment of Findings

To answer the research question RQ1 (*Which service characteristics of MODS affect the acceptability of the transport system?*) the results of Study 1 indicated that all six considered service characteristics affected the study participants' appraisal of the service concept. The DCE conducted in Study 1 found that respondents prefer short walking distances and are extremely sensitive to a prolongation of the time spent travelling. The analysis furthermore revealed that the overall perceived utility of the service increased as more information on the service was provided. In contrast, the perceived utility decreased when the departure time was postponed or when the operation required higher lead times for booking. In conclusion and to answer to RQ1, travel time, time of booking, walking distance, changing the point of departure, providing information and fare proved to affect the acceptability of MODS.

Study 1 also provided new insights into RQ1.1 (*In which way does the trip purpose, e.g., business trip, influence the travellers' appraisal of the service characteristics?*). It was shown that the purpose of the trip affected the choice behaviour in such a way that respondents who pictured the doctor's appointment were more attentive to the travel time and shifting the point of departure, indicating the relevance of a reliable and predictable service for trips with fixed dates. In contrast, the purpose of the trip showed no effect on the respondents' appraisal of fare, booking time and information provided. Based on the findings, it is thus important to study how reliability and predictability of service can be ensured, especially for trips with a less flexible arrival time and how users' trust in the service can be achieved. To conclude, the trip scenario affected the travellers' appraisal of some of the service characteristics of MODS (travel time and shift of departure) whereas other were not affected (fare, booking time and information provision).

In terms of RQ1.2 (*Are prospective users willing to pay for additional service characteristics, such as a door-to-door service?*), a major result was that the willingness to pay for service improvements depended on the purpose of the trip. Respondents who pictured the doctor's appointment were willing to pay an extra amount to reduce both the walking distance to the pick-up point and the travel time compared to the shopping trip scenario. Regardless of the reasons for travelling, respondents expressed their willingness to pay to avoid a shift of the time of departure and an increase of travel time. Conversely, the study indicated that monetary incentives might be a powerful measure to encourage travellers to share rides in MODS and thus provided an important basis for Study 3. The willingness to pay estimation further contributed to the derivation of practical recommendations for the design of a user-centred service of MODS. To conclude and to answer to RQ1.2, Study 1 found clear evidence for users' willingness to pay for additional service quality, especially a restriction of travel time increases and for avoiding shifts of departure time.

In terms of RQ2 (How can knowledge about MODS be communicated to prospective users without prior hands-on experiences to increase their conceptual understanding about the service concept of MODS and at the same time be used to facilitate their willingness to use MODS?)*,* Study 2 proved the serious game *B.u.S.* to be a suitable tool for increasing players' knowledge about MODS and improving their appraisal of them. The comparison of the serious game to an online research showed that the game contributed to participants' long-term retention of knowledge about the operational concept of MODS. The serious game evaluation study found clear indications for beneficial effects of the gamified approach to address the challenge of gaining sufficient conceptual comprehension of the system. Although, participants showed a greater disposition towards the system this did not translate into an increase in their actual use of the MODS. The gamified approach did not increase the willingness to use MODS. In conclusion, it was shown that the serious game approach was beneficial for improving study participants' knowledge about the concept of MODS but had no effect on the willingness to use such systems.

Regarding RQ3 (*Which financial compensation is needed to make a shared ride more attractive than the non-shared ride in AMODS?*), Study 3 developed the notion of WTA to determine travellers' compensation demands. The WTA described the amount of money the respondents of the survey would be willing to spend for a shared ride compared to a non-shared ride. Thus, the WTA describes a form of compensation. A cumulative distribution function showed, that in order to attract 90% of respondents to share a ride of 10 minutes, the discount should be 50% or more compared to a private ride. Study 3 thereby showed that financial compensations can be used to attract users to share rides in AMODS.

The results of the Study 3 also provided an answer to RQ3.1 (*How do travel time and detour factor affect the compensation demands of travellers?*). The SP experiment showed that the necessary compensation for attracting travellers to share rides in AMODS depended on the travel time and the detour factor. A longer time travelling and a higher detour factor increased respondents' compensation demands. Based on the regression function, a formula was described to determine the WTA depending on the detour factor and the travel time. In contrast to existing pricing schemes of MODS (Betzholz, 2017; Edelstein, 2019; Lyft, 2018), the findings imply a dynamic pricing model, that adapts itself to these factors. To summarize, an increase in travel time and of the detour factor increased the compensation demands of study participants.

In terms of RQ3.2 (*In which way do socio-demographic characteristics affect the compensation demands for shared rides in AMODS?*), Study 3 showed that gender, age and income had a significant effect on the WTA. To be more precise, the criteria of being male and young with a low income related to a higher WTA, indicating lower compensation demands for a shared ride. The results confirm previous findings in the context of autonomous bus shuttles that pointed to a greater acceptability and willingness of men (Fraedrich, Cyganski, Wolf, & Lenz, 2016; Lavieri & Bhat, 2018; Luchmann et al., 2019). Thus, the findings imply that socio-demographic characteristics affect the compensation demands for sharing rides with strangers in AMODS. Concluding, user research is challenged to determine measures to increase willingness to share trips in AMODS that address women and older users in specific.

Concerning RQ4 (*To what extent can information about fellow passengers contribute to increase travellers' willingness to share rides in AMODS?*), Study 4 had shown that the quality of the information provided was important in encouraging people to share rides and require lower compensation. In more detail, providing detailed information about fellow travellers reduced the compensation demands of travellers. The beneficial effect of information about fellow passengers on the willingness to share rides is most probably linked to an increased transparency and trust in the system (Morales Sarriera et al., 2017). However, further research is needed to validate the results in a more naturalistic setting.

Study 4 also provided empirical answers to RQ4.1 (*Which information about fellow passengers proves especially relevant for increasing travellers' willingness to share rides in AMODS?*). It was shown that not all levels of information provision contributed equally well to encourage travellers to share rides and require lower compensation. In more detail, full profile information proved to reduce the compensation demands. Providing a male name only, resulted in higher compensation demands compared to a female name. In contrast, no significant effect of gender information was shown when presenting a picture or a full profile. Interestingly, the effect is not based on female study participants showing lower willingness to share a ride with men when presented to a name only but be traced back to male study participants that showed a significant lower willingness to share a trip with men in terms of a lower WTA. The study could not provide explanations for this effect. Hence, research is requested to study the effect of gender information of fellow passengers on travellers' willingness to share a ride in more detail. A possible starting point for this research could be the fear of crime in public spaces and public transport and the crime statistics.

9.2 Structural Embedding of the Findings in Theoretical Models

As worked out in chapter 2.2, existing behavioural models for predicting mobility choices are limited in their capability to determine the user perspective on MODS and to close the research gaps presented in chapter 3.2. To approach the potential users' requirements on MODS, existing models must be extended to include the dimension of flexibility. The dimension of flexibility thereby includes facets of temporal and spatial flexibility, such as changes in travel time, uncertainty of arrival time and deviation of routes among others.

The aim of the dissertation was to fill the research gaps by extending existing models by the inherent dimension of flexibility of MODS. Based on the findings of the four research studies, several implications about the underlying psychological mechanisms of the adoption process of MODS can be derived. In the following, the revealed mechanisms and effects that are considered to expand the existing knowledge about the user perspective on MODS are discussed and combined into a new integrated research model (see Figure 8). Theoretical models of behavioural choice, such as pro-environmental behaviour, describe individual's choice process as a complex model based on internal and external factors (Kollmuss & Agyeman, 2002). Thus, the derived research model is based on two layers – the individual and the environment. The model is conceptualized for today's MODS that still base their service on a human driver. However, it can be assumed that it also fits for autonomous MODS. Under the condition of autonomous operation, the constructs that are related to travellers' uncertainty are expected to have an even greater impact on the intention to use AMODS.

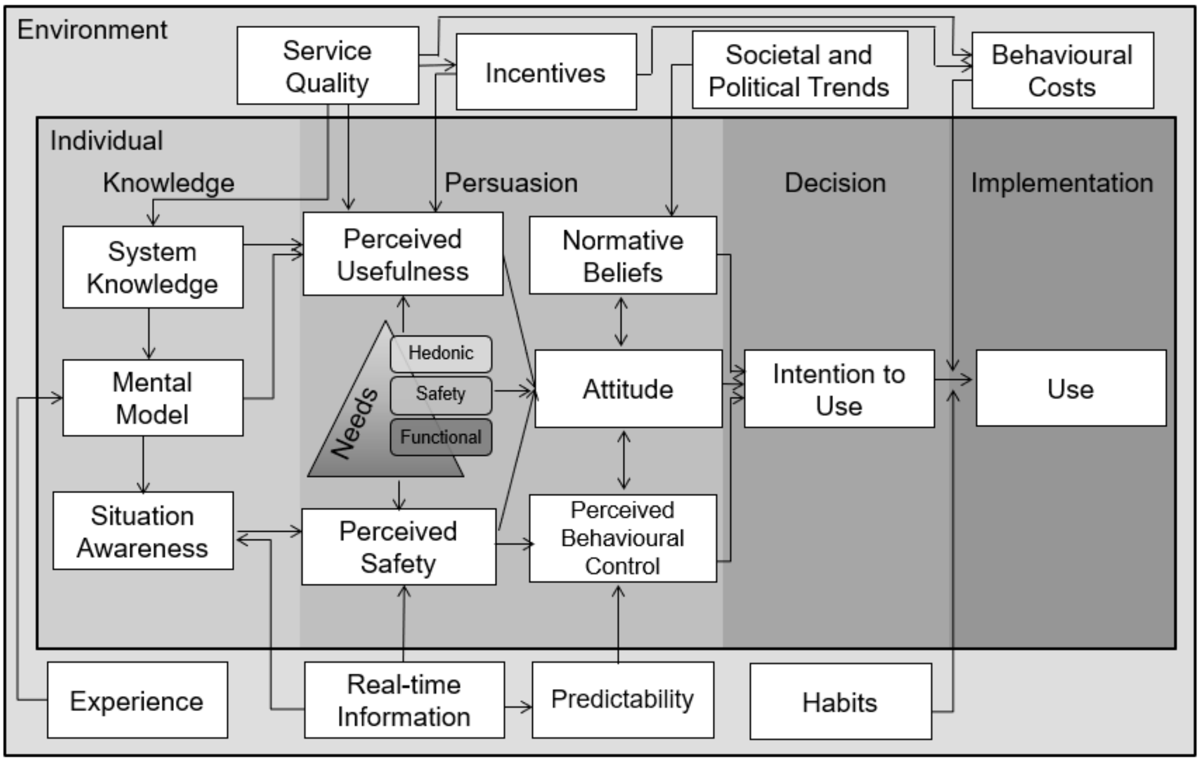

Figure 8. Proposed research model to approach individual's assessment of flexible public transport systems as an extension of the model of Diffusion of Innovation (Rogers, 2010), the Theory of Planned Behaviour (Ajzen, 1991), the Technology Acceptance Model (Davis, 1989) and the Hierarchy of needs (Maslow, 1943).

The proposed research model can be considered to be an extension of behavioural models for predicting mobility choices in the context of MODS. The model builds upon existing theoretical models: the Theory of Planned Behaviour (Ajzen, 1991), the Technology Acceptance Model (Davis, 1989), the Diffusion of Innovation Theory (Rogers, 2010), as well as an adaption of Maslow's (1943) Hierarchy of needs (Maslow, 1943). The proposed research model (Figure 8) pays particular attention to the flexibility dimension of MODS. This aspect is based on the dynamic changes in departure times, travel time and routes among others. It is expected to contribute to a decision-making process under conditions of uncertainty. The flexibility of the service concept of MODS and the associated uncertainty of users is reflected by different theoretical constructs that were added to the model and make the model stand out from the included models. These constructs are mainly system knowledge, mental model, situation awareness, real-time information and incentives are described in the following.

Awareness and knowledge of individuals are central determinants for the use public transport systems (Seebauer, 2011). Ensuring individuals' comprehension of the service concept is an essential prerequisite for the acceptability of the mobility service as shown in Study 2. The knowledge phase of the proposed model accounts for the challenge of a sufficient conceptual comprehension of the service concept of MODS. Travellers understanding of the service concept and the current state of the system can also be related to the concept of

Situation Awareness by Endsley (1995). The research model postulates two information constructs that affect the *Situation Awareness*: First, information about how the system works (*System Knowledge*), and second *Real-time Information* concerning the current state of service (e.g., route changes due to spontaneous boarding of passengers). The model proposes that System Knowledge is needed to build individual's *Mental Model* as a representation about how the system works (Norman, 2014). The Mental Model builds upon interactions with the system (Norman, 2014), meaning that previous experiences contribute to its formation. The Mental Model is expected to contribute to an individual's Situation Awareness that supports the assessment of the state of the service (e.g., route changes) and the projection of the status in the near future (e.g., delayed arrival). By providing meaning regarding the information at hand and therefore supporting decision-making (Endlsey, 1995), Situation Awareness can be proposed to affect *Perceived Behavioural Control* as another construct of the TPB.

Consistent with previous research in the field of transport mode choice and system acceptability (Bachmann, Hanimann, Artho, & Jonas, 2018; Bamberg & Schmidt, 1999; Haustein & Hunecke, 2007) *Perceived Behavioural Control* is supposed to be a direct determinant of the Intention to use MODS. The model assumes that the *Perceived Behavioural Control* is improved by the provision of *Real-time Information* on the service which increases *Predictability* and *Perceived Safety*. Based on Study 4, it can be assumed that the provision of information about the fellow travellers increases Predictability and subsequently the Perceived Behavioural Control. According to Wang et al. (2018), who found empirical evidence for a negative relationship between perceived risk and intention to use ridesharing, the model expects the construct of Perceived Safety to affect the individual's *Intention to Use* by increasing the Perceived Behavioural Control.

The serious game study (*Study 2*) found no evidence for a positive relationship between the construct *Perceived Ease of Use* and the intention to use the mobility-on-demand system. Perceived Ease of Use or its related construct Effort Expectancy failed to reveal as a significant predictor of Intention to Use in other studies in the context of transportation as well (König & Grippenkoven, in review; Wang et al., 2018). Diverging from the TAM, the construct of Perceived Ease of Use was thus not included in the model. However, it is supposed that the Perceived Ease of Use operates through other constructs, especially Perceived Behavioural Control and the Behavioural Costs (Byrka, 2009).

In accordance with the TPB of Ajzen (1991) the construct of *Attitude* is expected to affect the Intention to Use. Attitude was strongly related to the intention to use DRT in Study 2. The attitude towards the new transport system is expected to be affected by the individual's needs. Thus, Maslows (1943) Hierarchy of Needs, was added to the model as used before in transport research (Allen, Muñoz & de Dios Ortúzar, 2019; Singleton, 2013). Singleton (2013) included the hierarchy of travel needs to the Theory of Travel Decision-making. The proposed research model uses a recent adjustment of the Hierarchy of Needs in the context of mobility (Allen et al., 2019), that describes three types of attributes: functional, safety and hedonic. Moreover, it proposes that travel alternatives are evaluated based on a hierarchy of needs: Firstly, basic needs, such as functional needs and safety needs must be satisfied, before individuals strive for the satisfaction of hedonic needs. Hedonic Motivation, or users' enjoyment of the system, will have a strong impact on the intention to use automated road transport systems in the future, as shown by Madigan et al., (2017). Individual's needs affect and are affected by the Perceived Behavioural Control. *Perceived Usefulness*, a TAM construct, is also expected to be influenced by the individuals' needs.

In accordance with the Campbell Paradigm (Kaiser, Byrka, & Hartig, 2010), the construct of *Behavioural Costs* was added as a direct determinant of the intention to use. Behavioural Costs are the sum of costs, related to the realization of the behaviour (Byrka, 2009). These costs are a result of the service concept, such as a prolongation of travel time due to the pick-up of other passengers. These costs create a situational threshold that must be overcome by the individual's attitude (Taube, Kibbe, Vetter, Adler, & Kaiser, 2018). As an example, great behavioural costs due to a rather long walking distance to the pick-up point can be compensated by a positive attitude towards the economic and ecological advantages of ridepooling.

The model also includes *Habits*, that have been neglected in other models such as the TPB and the TAM (Chen & Chao, 2011; Klöckner & Blöbaum, 2010), but are expected to influence the decision-making process and the adoption of MODS. The relevance of mobility habits for the adoption of new services (Tsafarakis et al., 2019) and switching intentions toward public transport has been empirically proven before (Chen & Chao, 2011). Based on the results of *Study 2*, it can be assumed that habitual behaviour, such as frequent bike usage, can impede the use of MODS. Thus, the model proposes that Habits affect the relationship between the Intention to Use and the actual Use.

The research model further assumes that *Incentives* affect the Intention to Use. As shown in Study 3 and Study 4, financial incentives revealed to be an effective measure to increase individuals' willingness to share rides with strangers and accept longer rides. However, the model is not restricted to financial incentives. Non-monetary incentives might improve the willingness to use MODS, as well, but further research is needed to determine their impacts in the context of MODS.

This dissertation comprises of studies regarding internal factors such as perceived value of service quality attributes and utility (Study 1 and Study 3), attitudes (Study 2) and trust and perceived safety (Study 4). However, external factors, such as political and social factors (*Verkehrswende*, *FridaysForFuture*, car-free city centres etc.) have been mainly excluded from this research. Nonetheless, it can be assumed, that external influences from *Societal or Political Trends* and debates affect individual's perception of MODS through *Normative Beliefs*, such as in the TPB (Ajzen, 1991). The studies summarized in this dissertation could not provide empirical insights into the effects of environmental awareness or other Normative Beliefs. However, they are expected to play an important role in the proposed research model as they proved relevant in the context of users' perspective on carpooling (Bachmann et al., 2018). To conclude, the model, that was derived from the four studies, represents an approach to describe the psychological determinants of the adoption of flexible public transport systems (Figure 8).

9.3 Reflection of Restrictions and Limitations

For interpretation and reflection of the results, several restrictions and limitations of the research approaches must be critically reflected. Whereas study-specific limitations have been reflected in the respective research articles, the following subsection addresses more general limitations of the research approach.

Across all four studies, a key limitation is related to the challenge of creating an immersive research setting to achieve study participants' vivid imagination of (autonomous) MODS, even though they have not used or even heard about them before. In this context, the validity of online surveys for introducing futuristic products or services should be questioned even though they are a widely accepted tool to assess the prospective users' appraisal of autonomous vehicles (e.g., Alessandrini, Alfonsi, Delle Site & Stam, 2014; Bansal, Kockelman, & Singh, 2016; Fraedrich, Cyganski, Wolf, & Lenz, 2016; Tussyadiah, Zachl & Wang, 2017). The description of the service concept and the service attributes of MODS are a critical part of the study design of Study 1, Study 3 and Study 4. However, it is questionable if all participants understood them. Nevertheless, it is indispensable, that study participants understand the meaning of the attributes of MODS to be able to assess them. The studies addressed this challenge by excluding participants from data analysis that read the introduction pages too fast, which introduced the service concept of MODS and the use scenarios. Yet, a shortcoming of the study design is, that it is not possible to be sure that the respondents really understood the meaning of all attributes, especially *booking time* and *shift of departure* as these are not common service characteristics of regular public transport modes. Thus, the number of participants that did not have a clear view of the MODS, can only be estimated. Real-world studies that provide a more immersive study setting could be used to assess participants' willingness to share rides with strangers in autonomous vehicles, for instance. However, for the purpose of the dissertation – to approach the user perspective on flexible public transport – the survey-based approach was considered a worthwhile method to address first emerging research questions that did not demand the widespread availability of MODS and AMODS.

Another general limitation of the four studies was the selection of the study participants. The voluntary participation in the online surveys in Study 1, Study 3 and Study 4 should be scrutinized in the same way as the mandatory participation of the pupils in the serious game evaluation in Study 2. For online surveys, due to self-selection effects and the necessity of an internet connection, elderly and less educated people are frequently under-represented (Blasius & Brandt, 2010; Scherpenzeel & Bethlehem, 2011). So, the samples of the online studies of Study 1, Study 3 and Study 4 included very few older participants and a higher share of well-educated people. Study 4 even focused exclusively on representatives of Generation Y who are under 39 years. The presented results thus cannot be simply transferred to the whole population, but should be carefully interpreted taking into consideration the specific characteristics of the sample.

Furthermore, it should be emphasized that the scope of the findings is limited to the presented scenarios of the studies. The results are thus restricted to the trip purposes that were used in the experiments. Further research could assess whether the findings are transferable to other types of trips, such as regular commuting trips. Trip purposes will presumably have a strong impact on the model and the willingness to use it as trip purpose is closely related to the assessment of the service characteristics, such as travel time (Gim, 2018; Tyrinopoulos & Antoniou, 2013).

10. Conclusions

To conclude, in this chapter, implications for user-centred research on flexible public transport are derived and presented in the form of hypotheses. The chapter closes with a presentation of future research needs that result from the conducted research.

10.1 Implications for User-Centred Research on Flexible Public Transport

The aim of this dissertation was to study the adoption processes and underlying mechanisms of travellers' acceptability of a new, flexible mobility service concept – MODS. As outlined in chapter 1.2 and chapter 1.3, (autonomous) MODS are expected to have the potential to make an important contribution towards sustainable and user-centred mobility. However, the potential of new mobility services to contribute to the global goals of sustainability of the WHO (2018) can be depicted as the multiplication of the technical potential of the solution *and* the user adoption. This implies that the user perspective on new technology-driven solutions has to be given greater importance than at present for the transformation of the transportation sector. The objective of the partly explorative nature of this research was to acquire new insights into the requirements and needs of potential users of (autonomous) MODS. Hence, the findings of the four research studies form a basis for the formulation of hypotheses for more definite investigations. The conclusion is presented in the form of seven hypotheses that have been derived from this research.

It can be assumed that for MODS real-time information about the service replaces schedules and timetables of scheduled public transport. For autonomous MODS, mobility apps might serve as an alternative source of information to replace the absent driver. Thus, it can be concluded that real-time information becomes more important for users of (autonomous) MODS. User-centred research is therefore challenged to identify measures to create transparency and predictability of flexible mobility services. Conclusively, the following first hypothesis arise:

Hypothesis 1: Real-time information on the service operation is of particular importance for travellers' assessment of the service quality of MODS in the light of flexible routing and the lack of predefined schedules.

Choices under risk or uncertainty integrate information about the possible outcomes of the choice and the probability of each outcome (Rasouli & Timmermans, 2014a). The phenomenon of *loss aversion* of Prospect Theory postulated that losses loom larger than gains (Kahneman & Tversky, 1979). A transparent information provision about the possible outcomes of different alternatives (e.g., routes) could possibly help to create a realistic picture about the likelihood of the outcomes (e.g., delay) by reducing uncertainty. Providing travellers with up-to-date information about the ride (e.g., expected time of arrival) could thus counteract risk-averse behaviour and increase their willingness to choose the shared ride.

Hypothesis 2: Providing real-time information can contribute to increasing travellers' ability to assess for themselves the transport system by improving both their situation awareness of the situation and their understanding of the predictability of the service.

The increased relevance of providing information for travellers is accompanied by the need for a personalisation of the service. Giving regard to the finding that a shift of departure time and a prolongation of travel time negatively affected travellers' willingness to use MODS in Study 1, it might be recommendable to give users the control to decide for a maximum timing variation. To increase travellers perceived control over the system, the booking app could provide the possibility for the user to limit the maximum detour to know the latest time of arrival, to ensure the punctuality of appointments. It is also possible that users are offered the option to choose a 'women-only ride' or limiting the maximum number of fellow passengers to make them more comfortable.

Hypothesis 3: The great variability in travellers' assessment of predictability and reliability of service creates the need for customizing the service in terms of limiting the maximum allowed detour or maximum shift of departure time to increase user's control over the system.

Adding to the Hypothesis 2 and based on the results of Study 4, it can be concluded that providing detailed information about fellow passengers improves travellers' willingness to choose the shared option. But the study also revealed that different kinds of information have different effects on travellers' willingness to choose the shared option. As shown in Study 4, the provision of male gender information was related to a higher refusal rate of shared rides than female gender information. This was particularly relevant when only names were shown. The findings of this dissertation thus contribute to recent studies of Carol et al. (2019) and Morales Sarriera et al. (2017) that reported serious discrimination tendencies in the context of ridesharing. Study 4 added to these findings possible solutions to reduce discrimination of fellow travellers by providing information of a more personal nature (e.g., picture and rating).

Hypothesis 4: Travellers' attitudes towards choosing shared ride options are influenced by the information presented about fellow passengers. Acceptance rates are directly proportional to the quality of the information about fellow passengers: the more detailed the information the more likely the share option will be chosen.

A further hypothesis that emerges from the research is based on the findings of Study 3. It was shown that the scenarios that were characterized by a large deviation from the direct route from A to B led to the highest rejection rate of participants. In addition, individuals' assessments of different alternatives were strongly based on the way these alternatives and their characteristics were presented. As shown in Study 3, the zooming factor of the routes presented in the choice sets, was highly likely to contribute to the assessment of the duration of the trip and this affected the individual's final choice. Thus, it can be concluded that individuals base their choices not only on the attributes of the choice set, the information content, but also on the way the information is presented, the information context (Avineri, 2011). Hence, the presentation of information concerning a mobility service and the specific route can be considered to have a strong effect on travellers' behaviour.

Hypothesis 5: The way specific route suggestions and new flexible mobility services in general are introduced and presented to prospective users, affects their appraisal of the service and willingness to use it.

This dissertation assessed the possibility of monetary incentives to encourage travellers to share rides with fellow passengers and to serve as a compensation for travel time changes. The studies adopted the notion of WTA to investigate the adoption of shared rides. This methodological approach opened new possibilities for determining the effects of different service characteristics on the individual's appraisal. The analysis showed that fares could be used as an effective measure for compensation. Such pricing schemes should consider the original duration of the trip and the changes that ensue due to the shared service concept. In addition, a higher discount is needed to attract travellers to share rides if travel time and detour factors increase. It can be further assumed, that this pricing system has to be transparent to experience a high user acceptance and to serve as an efficient incentive to choose the shared option. As an example for lacking transparency of the pricing system, the mobility-on-demand provider *Lyft* explains only vaguely on its website: “Prices for rides are dynamically calculated based on a variety of factors including route, time of day, ride type, number of available drivers, current demand for rides, and any local fees or surcharges” (Lyft, 2018).

Hypothesis 6: Dynamic pricing systems, that consider travel time changes, could be used as an effective measure to compensate for the drawbacks of shared rides.

The many dimensions the user perspective on MODS calls for multidimensional methodologies to study these systems. This dissertation thus adopted methods from psychology, behavioural economics (WTA) and educational science to study the user perspective on these new services. Especially, for AMODS, with their technology still in its infancy, new and immersive research methods are needed to study user acceptability. Immersive study settings proved important to facilitate a realistic understanding of AMODS, e.g., in terms of their perceived usefulness (Distler et al., 2018). Study 3 and Study 4 used a realistic image of a booking app to present the choice scenarios. However, facilitating users' real interaction with the transport service was not possible. Factors that proved significant for acceptability of AMODS, like perceived safety (Grippenkoven et al., 2019; Roche-Cerasi, 2019), are difficult to study in less immersive settings.

Hypothesis 7: Emerging transport systems such as AMODS demand immersive research methods that facilitate an almost realistic user experience.

10.2 Future Research Needs

This dissertation ends with the accentuation of future research needs that arise from the four presented studies. On the one hand, several research questions, that were posed in the introduction, could not be addressed by this dissertation or are not answered by the findings to a satisfactory outcome. On the other hand, as an inherent characteristic of explorative research approaches, several new research questions were revealed in the research process. The following paragraphs introduce the research questions that were raised by the dissertation itself, along with suggestions for the methodological research approaches that would help to answer them.

First of all, the denomination of the new mobility concept of MODS demands for research on the **definition and wording** of such new systems. This dissertation applied several technical terms to describe flexible and shared mobility concepts, such as mobility-on-demand, ridepooling or demand-responsive transport. Even more are used by mobility providers, transport authorities and the media. However, a consistent and if possible, self-explanatory wording is essential for a clear distinction between different service concepts and for supporting the establishment of a mental model of potential users concerning the mobility service. “Consistent definitions across a suite of shared mobility service models can guide public policy and distinguish between types of services for users” (Shaheen & Cohen, 2018, p. 1). Further research is thus challenged, to study the denomination of the service concepts for potential users’ understanding of the service and their acceptability.

Related to the aforementioned research need is the task to ensure **transparency and predictability** of the service. User-centred research is challenged to determine the factors that contribute to the understanding of the flexible service concept of MODS, that entail spontaneous variations from the defined route and the travel time due to the pick-up and drop-off of other passengers. Improving travellers’ understanding of the service concept can be related to the concept of SA by Endsley (1995) as deduced in section 2.1. Because MODS waive fixed schedules and routes, further research is needed to determine to what extent a comprehensive, real-time information provision about the route, stops and fellow passengers can improve the SA and PBC of travellers. It can be expected that this question gains particular relevance for autonomous systems, as there is no driver to ask for information.

Study 2, Study 3 and Study 4 of this dissertation can only be considered as a beginning of the research on individuals’ increased **information needs** concerning the new mobility concept of MODS. More empirical studies are needed to assess individuals’ requirements for information concerning the service. Based on the research gap, the question arises, how the traveller can be supported in his or her new role as a *prosumer* of mobility. Inspired by the energy market (cf. Brown, Hall, & Davis, 2019), prosumers are active consumers that produce and consume, and thereby actively shape their environment, like the transport operation. Accordingly, it appears interesting to study the information needs and necessary tools of these prosumers. Adding to these information needs, further research is needed on how travellers can be supported in finding the *virtual bus stops* that will be used by MODS to reduce walking distance and to efficiently match ride requests (Nationale Plattform Zukunft der Mobilität, 2019). And furthermore, it would be interesting to investigate, how an *Artificial Intelligence* (AI) might support individuals’ mobility as a personal travel manager, in accordance with the concept of *Mobility-as-a-service* (Maas). To conclude, several research issues are raised that deal with the increasing information needs of users of MODS and touch topics such as intelligent travel assistants.

Based on the findings of Study 4 and further studies that found some resistance to share rides with strangers (Amirkiaee & Evangelopoulos, 2018; Lavieri & Bhat, 2018; Morales Sarriera et al., 2017; Nielsen, Hovmøller, Blyth, & Sovacool, 2015), more research is needed to study the factors that affect the willingness to share rides with strangers. Accordingly, another branch of research opens concerning the **perceived safety** of passengers of AMODS. The need for studying determinants of passengers safety assessment is highlighted by the statements of study participants of Study 3, when asked for a concluding comment at the end of the study: „*I would never use an autonomous taxi with other unknown passengers. It is not a question of price, i.e., even if I had little money, I would not use it for the sake of my safety. A camera in the vehicle would not change it either. I would probably use it alone*" (female, 55 years, translated from German). Also, male respondents revealed scepticism towards a ride with fellow passengers: „*These things are supposed to drive autonomously. The other passenger could be female. I won't sit in a vehicle with a strange woman without witnesses. That's pure self-protection"* (male, 56 years, translated from German). In this context, assessing the possibilities of improving passenger safety through countermeasures, such as a remote-control centre (Grippenkoven, Fassina, König & Dreßler, 2019), should be considered as another task for research.

Study 4 of the dissertation focussed on the effect of providing information on fellow passengers on the willingness to share rides. It revealed a significant effect of the gender of the fellow passenger on the willingness to share rides. Giving the fact that empirical studies point to **tendencies of discrimination** in the context of ridesharing, based on social class (Moody, Middleton, & Zhao, 2019) and different ethnicities (Carol, Eich, Keller, Steiner, & Storz, 2019; Moody, Middleton, & Zhao, 2019), further research is needed to examine these effects for MODS, especially autonomous systems. If further research confirms discriminatory tendencies due to age, gender, social class or cultural background for autonomous MODS, further research is needed to determine means for preventing discrimination when using the system.

This dissertation also leaves several questions concerning the **attitude-behaviour gap**, that describes the divergence between the expressed willingness to use a system and the actual use (Byrka, 2009). Based on the serious game evaluation study, it seems to be of great interest to examine the inter- and intrapersonal factors that moderate the relationship between the willingness to use MODS and its actual usage. Moreover, it can be assumed that environmental conditions, such as the place of residence and the availability of a bicycle, play an important role for the realization of intentions to change mobility behaviour, as shown in Study 2. Thus, environmental constraints and facilitators, which are defined as behavioural costs in the *Campbell Paradigm* (Taube et al., 2018), need further studies in the context of MODS. Hence, external factors, such as political and societal trends, described in the research model in Fig.8 should be considered in future studies of transport mode choice.

Related to the factors that affect travellers' willingness to share trips with fellow travellers, another branch of research emerges, that addresses **incentives and nudging** for behavioural change. *Nudges*, which are defined as "liberty-preserving approaches that steer people in particular directions" (Sunstein, 2014, p. 583), could help individuals to overcome cognitive biases and influence their travel behaviour and mode choices (Fuji & Taniguchi, 2006; Harries, Eslambolchilar, Stride, Rettie, & Walton, 2013). This dissertation focussed on financial benefits as a compensation for sharing rides in MODS, but several other mechanisms and persuasive techniques could be worth further exploration for increasing individuals' willingness to use MODS. To name one example, an increased societal environmental consciousness could be used to nudge individuals to adopt sustainable transportation habits by framing the sharing of rides as ecologically friendly (Alemi, Circella, Handy, & Mokhtarian, 2018). Based on the assumptions, that travel mode choices can be considered as a social dilemma and that transport-related costs are mainly seen as a 'social' cost rather than a 'private cost' (Avineri, 2011), the activation of salient social norms could encourage individuals' prosocial behaviour, according to the Norm Activation Theory by Schwartz (1977). The question arises, how a social credit system, like *karma points* and gamification, could be used for changing travel behaviour towards more sustainable transport modes.

Further research is needed regarding the service quality of MODS. Study 1 attempted to determine the users' appraisal for **inherent service characteristics** of MODS. Yet, the results represent only a starting point for further research that should focus on the question of how much flexibility a traveller is 'able to bear'. In addition to this, the question arises, what the maximum detour factor is, that is acceptable to travellers. To complement the findings of Study 1 and Study 2, further research on the question, how travellers deal with spontaneous changes of the arrival time, would be necessary. A question that remains unanswered is, whether they understand the system inherent necessity of dynamic route changes. On this basis, a potential research question emerges on how to impart knowledge about the flexibility of the service concept and consequently increase comprehension and acceptance.

Due to the novelty of the service concept of MODS and the disruptive potential of AMODS, voices of policy and research have been raised claiming the participation of parties concerned, especially the potential users, in the design and development process of new mobility systems and infrastructure projects (Brake, 2004; Federal Ministry of Transport and Digital Infrastructure Germany, 2014; Schiefelbusch & Dienel, 2009; VDI, 2015). An interesting methodological starting point for further research is the application and further development of **participatory approaches** in the context of (autonomous) MODS, such as *co-creation* (Defila & Di Giulio, 2018) and *real-world laboratory* (Gebhardt, Brost, & König, 2019). The involvement of users would possibly facilitate individual's interest in a topic and contribute to identify and specify implicit user requirements as well as subsequently to co-create ideas and concepts (Lai & Chen, 2011; Mitchell et al., 2016).

Related to the topic of user involvement is the challenge of **creating immersive study settings** to facilitate the visual aspect and to give a clear notion of such new services, that are still not on the market, which means that study participants have no experiences of them (see section 2.2). Psychological research that addresses future transport systems is thus challenged to develop and apply new research methods to give people a more vivid idea of the service, such as virtual reality studies, serious games and the *Wizard-of-Oz* technique (cf. König, Dreßler, Brandenburger, & Grippenkoven, 2020).

Finally, one of the most challenging issues for future research is to validate the findings in **real-world experiments and field studies**. Further studies could replicate the SP experiments in a real-world situation. For example, the choice experiment concerning the willingness to share rides with fellow passengers, could be replicated in a study using an autonomous public transport system to verify the stated preferences of participants. Field studies would give study participants the chance to interact with real vehicles and other passengers and thus would most likely improve the external validity of the study results in terms of perceived safety and willingness to use among others.

To conclude, only the widely available operation of MODS and AMODS will validate the findings of the empirical studies presented here. As shown in the preceding chapter, a multitude of research questions were raised by the four studies and still remain unanswered. However, at this stage, the findings of the four studies provide insights into the requirements and needs of the prospective users of MODS and AMODS and thereby lay a foundation for their adoption later on.

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Attachments

Attachment A - Publication 1

König, A. & Grippenkoven, J. (2019). Modelling travelers' appraisal of ridepooling service characteristics with a discrete choice experiment. *European Transport Research Review, 12*(1). https://doi.org/10.1186/s12544-019-0391-3

A.K. provided the research idea.

A.K. prepared these samples

A.K. developed method XY

A.K. programmed software and performed simulations.

A.K. designed / planned / executed the study

J.G. gave research assistance.

J.G. gave methodological advice.

A.K. conducted the measurements.

A.K. took part on the data collection.

A.K. analyzed the data

J.G. supported the data analysis.

A.K. wrote the manuscript.

J.G. contributed to writing and improving of the manuscript.

J.G. contributed to revising the manuscript.

A.K. supervised the project.

J.G. gave scientific advice / constructive feedback

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ORIGINAL PAPER Open Access

Modelling travelers' appraisal of ridepooling service characteristics with a discrete choice experiment

Alexandra König* and Jan Grippenkoven

Abstract

Background: Ridepooling services have been predicted a bright future since they promise a flexible and user-centered mobility service. However, there is a research gap in examining the travelers' perception of ridepooling service characteristics since findings concerning fixed-scheduled public transport are hardly transferable.

Methods: In order to shed some light on the human factors of ridepooling services a Discrete Choice Experiment ($N = 410$) was performed to identify travelers' preferences concerning ridepooling's service features. The study thereby focusses on the effect of trip purpose on the appraisal of the service attributes. Based on a literature review and a focus group six attributes of the operational concept were determined: fare, walking distance to the pick-up point, time of booking in advance, shift of departure time, travel time and information.

Results: The results underline that all of the six attributes significantly affected choice behavior. The appraisal of the service characteristics differed depending on the presented trip purpose. The willingness to pay was calculated for each service characteristics. The results give guidance for the user-centered design and operation of ridepooling systems that meet the requirements of the prospective passengers and thus facilitate behavioral shifts towards more sustainable mobility systems.

Keywords: Digitalized transport, Discrete choice experiment, Passenger perspective, Mobility on demand, Shared mobility

1 Introduction - benefits of Ridepooling

In the light of the steadily increasing number of passenger transport by private car [1] the development of shared mobility solutions has become an important field for research and transport providers [2]. Recent simulation studies have shown that the number of vehicles in cities could be reduced to a small proportion of nowadays vehicle fleet by the deployment of a shared (autonomous) vehicle fleet that pools ride requests of travelers and thus contribute to a reduction of traffic volume and the related emissions [1, 3, 4]. A variety of new mobility services is emerging within the range between conventional public transport and individual transport, facilitated by the rapid growth of information technology and digitalization [5]. Ridepooling concepts provide on demand public transport services without fixed schedules and predefined stops by using digital booking and intelligent matching algorithms to pool the routes of passengers that are heading the same direction [6]. For passengers, ridepooling services provide flexible and personalized mobility by adapting time and pick-up point of the ride to the actual needs of the travelers [1]. Ridepooling schemes have existed for decades under the name of *demand-responsive transport* (DRT) in rural areas. A factor that counteracted a widespread operation of DRT services was the disproportionate effort that had to be invested by the users for booking and for service providers for route planning and management [7]. Nowadays, the rapid development and spread of information technology enables improved service efficiency and advances the provision of mobility on demand [8].

A large number of ridepooling services were launched during the last years, like *Kutsuplus* in Helsinki [9] or *ioki* in Hamburg ([10], July 16).

* Correspondence: alexandra.koenig@dlr.de
Institute of Transportation Systems, German Aerospace Center (DLR e.V.), Lilienthalplatz 7, 38108 Braunschweig, Germany

However, those services are in most cases not accompanied by sufficient scientific research [11]. As Tsafarakis et al. [12] state, research still knowns little about the complexity of users' preferences regarding new mobility services, especially with regard to innovations in public transport. There is little information about how these new digitalized and flexible mobility services are used and how they may affect travel behavior, which is posing challenges for transport planners and researchers [11]. The article builds up on a related work by the authors concerning urban residents' appraisal of ridepooling systems and the associated service attributes [13]. The study that focused on city dwellers only, assessed the relative importance of the service characteristics for the participants' appraisal of the ridepooling service by addressing the research question: "door-to-door-service or fare?" The study found that the answer to the question depends on the sociodemographic factors of the person considered – while fare was the most important service characteristic for younger individuals, elderly paid more attention to short walking distances to the pick-up point [13]. Yet, the study leaves the question open whether the findings can be transferred to a broader population. Furthermore, the prior study lacks an in-depth preference measurement based on regression analysis and willingness to pay assessment.

Before launching another ridepooling service there is a clear need for comprehensive research on the factors that affect the adoption of such systems. Hence, the study of travelers' requirements concerning ridepooling services is a necessary precondition for a user-centered design of ridepooling service concepts and their adoption. This article was developed on the basis of limited findings concerning travelers' preferences regarding ridepooling service concepts and the need to study users' preferences concerning innovations in public transport [12]. In order to address this research gap the article pursues three goals:

- To identify which service characteristics of ridepooling services affect travelers' appraisal of the ridepooling system.
- To examine the effects of trip purpose on the choice behavior of prospective users.
- To assess the prospective users' willingness to pay for different service characteristics of ridepooling systems.

2 Literature review

A literature review was conducted to determine the factors that have proven to affect travelers' appraisal of service characteristics of fixed-scheduled bus transport and thus might affect travelers' perception of a ridepooling's service concept. Therefore, attributes concerning the vehicle concept and the stop environment were not focus of the literature review. Regarding the limited number of empirical results concerning the operational service concept of ridepooling, the literature review was extended by studies on fixed-scheduled bus transport. In summary, the literature review revealed the importance of ten recurring attributes on travelers' appraisal of the service concept of public transport as shown in the Table 1.

Since ridepooling services are in large parts very different from fixed-scheduled public transport, the transferability of study results concerning travelers' appraisal of fixed-scheduled public transport service characteristics to new digitalized transport services is limited. For instance, as shown in Table 1, several studies emphasize the importance of reliability and punctuality for travellers' appraisal of public transport systems [14, 22–25]. For ridepooling systems, punctuality is presumably still important. However, in such flexible mobility services the criterion of punctuality will rather be related to a dynamic prognosis of the arrival time of a vehicle than to a fixed schedule determined to fixed stops.

Further service characteristics that have been proven to affect travelers' appraisal of public transport services like service frequency [21], speed [14] and service provision hours [15] have to be adapted to ridepooling concepts that waive fixed service elements in favour of flexible demand-responsive service elements. In the light of the absence of a fixed time schedule and route plan for ridepooling concepts travelers' information needs concerning the flexible route and the time of arrival among others are supposed to increase.

The timely and spatial flexibility of ridepooling schemes is expected to be attractive for certain trip purposes whereas the system immanent dynamic of service is supposed to be perceived as a critical factor for timely fixed trip. Since factors like the experience of time pressure and the need for punctuality strongly depend on the trip purpose, the contextual factor of trip purpose is supposed to strongly affect the travelers' appraisal of the ridepooling service characteristics. Therefore trip purpose might play an important role in the assessment and adoption of the demand-responsive mobility concept. The importance of trip purpose on the modal choice and value of travel time was emphasized before in literature concerning public transport [27, 29] as well as new mobility concepts like autonomous driving [30]. Thus, trip characteristics like time pressure have to be considered when analysing travelers' appraisal of ridepooling.

Table 1 Results of literature review concerning attributes affecting travelers' perception of bus service quality

Attributes	Sources
Reliability/ on-time performance/ punctuality/ waiting time/ regularity/ timeliness	Beirão and Cabral [14], Bourgeat [15, 16], Dell'Olio, Ibas and Cecin [16], De Oña, De Oña, Eboli, and Mazzulla [17], De Oña, de Oña, Eboli, Forciniti, and Mazzulla [18], Diab, van Lierop, and El-Geneidy [19], Eboli and Mazzulla [20], Eboli and Mazzulla [50], Hansson et al. [21], Hensher and Prioni [22]; Jianrong et al. [23], Paulley et al. [24], Redman et al. [25], Tyrinopoulos and Antoniou [26], Tyrinopoulos and Antoniou [27]
Frequency	Bourgeat [15], De Oña et al. [17], Eboli and Mazzulla [20], Eboli and Mazzulla [50], Hansson et al. [21], Hensher and Prioni [22], Knapp (1997), Mazzulla and Eboli [28], Redman et al. [25], Tyrinopoulos and Antoniou [26]
Travel time/ speed/headway/time	Beirão and Cabral [14], Bourgeat [15], De Oña et al. [17], De Oña et al. [18], Diab et al. [19], Hansson et al. [21], Hensher and Prioni [22], Jianrong et al. [23], Knapp [51](1998), Redman et al. [25]
Fare/price	De Oña et al. [17], Eboli and Mazzulla [20], Hansson et al. [21], Hensher and Prioni [22], Jianrong et al. [23], Knapp [51](1998), Paulley et al. [24], Redman et al. [25], Tyrinopoulos and Antoniou [26]
Information provision/real-time information	Beirão and Cabral [14], Bourgeat [15], De Oña et al. [17], Eboli and Mazzulla [50], Hansson et al. [21], Hensher and Prioni [22], Mazzulla and Eboli [28], Paulley et al. [24], Redman et al. [25], Tyrinopoulos and Antoniou [26], Tyrinopoulos and Antoniou [27]
Walking time to access/ proximity of stops/ access and egress time	Bourgeat [15], De Oña et al. [17], Eboli and Mazzulla [20]; Hensher and Prioni [22]; Paulley et al. [24], Jianrong et al. [23], Tyrinopoulos and Antoniou [26]
Number of stops	Knapp [51](1998), Mazzulla and Eboli [28]
Service provision hours/ operating hours/ operating period/ last bus	Bourgeat [15], De Oña et al. [17], Knapp [51](1998), Tyrinopoulos and Antoniou [26]
Network coverage	Tyrinopoulos and Antoniou [26]
Connectability/ Number and quality of interchanges/Integration of network	Beirão and Cabral [14], De Oña et al. [17], De Oña et al. [18], Hansson et al. [21], Paulley et al. [24]

3 Methodology

3.1 Discrete choice experiment to model travelers' preferences

To address the stated research aims a Discrete Choice Experiment (DCE) was applied [31]. DCE bases on the Random Utility Theory (RUT) and proposes that individuals strive for utility maximization [31]. In DCE, the decision-maker is confronted with choice sets that consist of different alternatives, which are characterized by a set of attributes. The relative importance of the attributes is elicited by presenting a series of choice sets with varying attributes' levels to the individual [32]. Due to their strengths in eliciting preferences DCE are applied in a considerable number of research domains like transportation [30].

3.2 Selection of attributes and levels for DCE

Literature outlines the importance of a comprehensive process for the definition of attributes of a choice experiment since the results highly depend on the selected attributes [32]. A two-stepped method was chosen for identifying attributes and corresponding levels as proposed by Dell'Olio et al. [16]. Based on the identified attributes of a literature review (Table 1), a focus group with 9 participants (female = 6, $M = 51.67$ years, $SD = 22.5$ years) was conducted to validate the results of the literature review, to identify and include additional attributes relevant to ridepooling services and to exclude irrelevant attributes [33]. Furthermore, maximum acceptable levels, so called *knock out criteria* were assessed [34] and appropriate terms for the attributes were specified that correspond to the actual vocabulary of the prospective users [32].

For selecting the final attributes and levels for the DCE the guidelines of Weiber and Mühlhaus [34] were considered. Out of the ten attributes identified in the literature review *frequency, service provision hours, network coverage* and *number of stops* were excluded from further investigation since ridepooling systems are not based on a fixed timetable. *Reliability* was renamed *shift of departure time* since there is no predefined schedule in ridepooling systems. *Shift of departure* was defined as the shift of the actual pick-up time caused by the ad hoc access of further passengers. *Time of booking* was added as attribute because the service concept of ridepooling requires a certain time interval of booking a ride before being picked up in contrast to the conventional forms of public transport. This attribute describes the minimal number of minutes required to book a ride before departure. The attribute *travel time* describes the total duration of the ride that might be prolonged by a detour due to the access and egress of other passengers. *Information provision* proved to be an important attribute for travelers' perception of bus transport and is supposed to be an important attribute of ridepooling concepts as well. The three levels of *information provision* differ in the quantity and real-time of information provided: 1) *None*: No information about the

Table 2 Final attributes and corresponding levels used for DCE

		Attribute					
		Time of booking (min)	Walking distance (m)	Shift of departure (min)	Travel time (min)	Information provision	Fare (€)
Level	1	5	0	0	10	None	2.50
	2	10	300	10	20	Few	3.00
	3	30	500	20	30	Much	3.50
	4						4.00

details of his journey are provided, 2) *Few*: the traveler receives few information about the journey, e.g. approximate time corridor of arrival, 3) *Much*: the user is provided with detailed and real-time information about the journey, e.g. map with route and real-time arrival time. Table 2 lists the final set of attributes and their corresponding levels used for DCE.

3.3 Experimental choice design

A fractional factorial design according to Aizaki, Nakatani, and Sato [35] was used to reduce the total number of possible ridepooling schemes to a subset of 24 choice sets as respondents can handle about 30 choice situations [36]. The study was performed as an online survey using the software SosciSurvey [37].

The respondents were introduced to one of two ridepooling scenarios (between-subjects-design): 1) a *shopping trip* to the city center on a weekday's afternoon with the trip purpose to buy a gift card and 2) a *doctor's appointment* at a weekday's afternoon. Since this scenario indicated a fixed appointment, time pressure was supposed to be higher than in the shopping scenario. The distance of both rides was set to 5 km. As proposed by Bahamonde-Birke, Navarro, and de Dios Ortúzar [38] respondents were offered a *none-of-these option* to avoid a forced choice. Each choice set consisted of two alternatives and the opt-out option (Fig. 1). Before presenting the 24 choice sets in random order, the six attributes and levels were introduced to the participants with the help of graphical and textual descriptions.

3.4 Data analysis

Data were analyzed with the help of Mixed Multinominal Logit (MMNL, [39]) that represents the current state of the art for modelling DCE [40, 41]. MMNL differ from Multinominal Logit (MNL) because of the inclusion of random coefficients that are drawn from a cumulative distribution function arising from taste heterogeneity in a population [39]. MMNL recurrently result in a substantial improvement of fit over the MNL model because of the increased explanatory power of the specification [41]. MMNL represent a mixture of alternative-specific and case-specific regressors and account for the panel structure of the data [40]. Since MMNL does not demand the independence from irrelevant alternatives and account for correlations in unobserved utility panel data can be analyzed that base on the repeated choices of the decision-makers [39]. MMNL is consistent with Random Utility Theory (RUT, [31]). RUT proposes that individuals will choose the alternative with the highest subjective utility U that is described as the sum of an observed component V and a residual component *e.* As shown in (1), the observed component of utility V that represents the overall worth of an alternative j is defined by the sum of the part-worths *ß* of its attributes where x_{nsjk} is a vector of k attributes [36]. Those parth-worths *ß* are preference weights that represent the contribution of the attribute to the utility of an alternative.

$$V_{nsj} = \sum\nolimits_{k=1}^{K} \overset{\tilde{A}}{O}_k x_{nsjk} \quad (1)$$

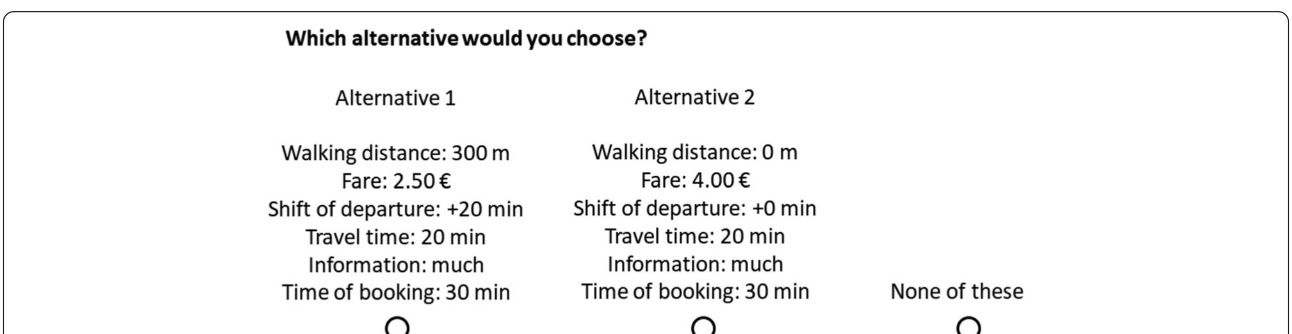

Fig. 1 Example of a choice set of the DCE (translated from German)

MMNL was performed with the statistical software *R* [42] using the *mlogit* function [43].

3.5 Sample description

After the exclusion of 111 respondents (21.3%) that took less than two minutes to read the instructional pages the final sample size was $N = 410$. The sample was characterized by a mean age of 45.3 years ($SD = 17.2$ years) and consisted of slightly more men ($n = 234$, 57.1%) than women ($n = 166$, 40.5%, rest missing). See Table 3 for a detailed description of the sample. The participants came from all over Germany, with a high share of respondents living in the highly-populated states of Lower Saxony (20.2%), Baden-Wurttemberg (12.9%) and North-Rhine Westphalia (11.2%). A total of 88.8% had a driver's license and 81.2% owned a car in their household. The majority of the respondents declared that they had heard about demand-responsive-transport-systems (79.0%) and 17.9% stated to have used such a transport system at least once in their life.

4 Results

4.1 Model specification

A total of 29,520 observations (410 respondents × 3 alternatives × 24 choice sets) were incorporated in the estimation of the model. The opt-out alternative was treated as the reference alternative within the model. The panel dimension of the data was taken into account by adding an argument to the model.

The assumptions for logistic regression were checked. The model including all of the six attributes revealed a high model fit as shown by *McFadden* $R^2 = 0.29916$ that lies within the required range between 0.2 and 0.4 [39]. The model's log-likelihood value was − 7257.9 and the likelihood ratio test was $X^2 = 6196.1$ ($p < .001$). The *Akaike Information Criterion* was $AIC = 14{,}543.72$ [36]. For each

Table 3 Sociodemographic characteristics of the sample ($N = 410$)

Sociodemographic variable	Characteristics	n	%
Gender	Male	234	57.1
	Female	166	40.5
	Missing	10	2.4
Age	< 30 years	96	23.4
	30–44 years	107	26.1
	45–59 years	100	24.4
	> = 60 years	101	24.6
	Missing	6	1.5
Size of residence (number of inhabitants)	< 10.000	88	21.4
	10.000–50.000	83	20.2
	50.000–500.000	158	38.6
	> 500.000	74	18.1
	Missing	5	1.2
Highest educational level	No educational qualification/still in education	5	1.2
	Secondary school certificate	46	11.2
	High school graduation	94	22.9
	Vocational training	39	9.5
	University degree	220	53.7
	Missing	4	1.0
Employment status	Full-time	186	45.4
	Part-time	47	11.5
	Unemployed	7	1.7
	Retired	80	19.5
	In education	73	17.8
	Temporary out of work	9	2.2
	Home-maker	2	0.5
	Missing	4	1.0

Table 4 Results of mixed multinominal logistic regression

	Full model				Doctors' appointment				Shopping trip			
	coefficient	SE	z-value	*p*	coefficient	SE	z-value	*p*	coefficient	SE	z-value	*p*
B:intercept	12.33443	0.2026	60.887	<.001**	10.1899	0.3332	30.581	<.001**	11.9405	0.2911	41.019	<.001**
C:intercept	13.16533	0.2389	55.097	<.001**	10.8413	0.3889	27.872	<.001**	12.7269	0.3445	36.945	<.001**
Fare	−0.02785	0.0006	− 48.201	<.001**	− 0.0189	0.0009	−20.754	<.001**	−0.0282	0.0008	−33.294	<.001**
Walking distance	−0.00369	0.0001	−33.189	<.001**	−0.0031	0.0002	−17.492	<.001**	−0.00255	0.0001	−17.089	<.001**
Time of booking	−0.01775	0.0018	−9.6752	<.001**	−0.0089	0.0030	−2.963	0.003	− 0.01687	0.0026	−6.4812	<.001**
Shift of departure	−0.10704	0.0026	−40.559	<.001**	−0.1048	0.0045	−23.529	<.001**	−0.09778	0.0038	−26.007	<.001**
Travel time	−0.09282	0.0029	−32.300	<.001**	−0.0911	0.0049	−18.521	<.001**	−0.08053	0.0039	−20.512	<.001**
Information	0.629217	0.0243	25.882	<.001**	0.40392	0.0406	9.959	<.001**	0.56814	0.0356	15.980	<.001**
sd.Fare	0.004953	0.0001	38.034	<.001**	−0.0076	0.0003	−24.437	<.001**	−0.02042	0.0006	−36.477	<.001**
sd.Walking distance	−0.01187	0.0003	−36.499	<.001**	−0.0032	0.0002	−14.838	<.001**	− 0.00375	0.0001	−20.943	<.001**
sd.Time of booking	0.00624	0.0028	0.2202	<.001**	−0.0156	0.0039	−3.904	<.001**	−0.02071	0.0031	−6.5998	<.001**
sd.shift of departure	−00.01857	0.0033	−5.6015	.8257	−0.0699	0.0052	−13.544	<.001**	−0.04430	0.0039	−11.481	<.001**
sd.Travel time	−0.02192	0.0024	−8.9778	<.001**	−0.0393	0.0036	−10.872	<.001**	−0.00178	0.0032	−0.5471	0.5843
sd.Information	0.024754	0.0304	0.8118	<.001**	−0.3889	0.0315	−12.332	<.001**	−0.34454	0.0026	−13.051	<.001**
Log-likelihood	−7257.9				− 2951.2				− 3770.9			
McFadden R^2	0.29916				0.37792				0.32788			
Likelihood ratio test (X^2)	6196.1				3585.8				3679.2			
AIC	14,543.72				5930.47				7569.83			

Notes: *ß* = coefficient, *SE* = standard error coefficient *p* = *p*-value, ** = *p* < .001

of the scenarios a separate model was computed. The three models (*full model*, *shopping scenario* and *doctor's appointment scenario*) are presented in Table 4.

4.2 Preference measurement

Table 4 shows the results of MMNL. The coefficients reflect the attributes' contributions to the overall utility [36]. For the full model, all coefficients significantly contributed to the overall utility as shown by a significant p-value of p < .05. Apparently, the respondents' choice is based strongly on all of the six service attributes. As shown in Table 4, respondents are attentive to the fare of the offered service (ß = − 0.0279, p < .001). As shown by the negative sign, the overall utility of the ridepooling service decreases when price increases. Furthermore, respondents are very sensitive to increasing walking distances (ß = − 0.0037, p < .001), shifts of departure (ß = − 0.107, p < .001), a prolongation of travel time (ß = − 0.0928, p < .001) and a higher lead time for bookings (ß = − 0.0177, p < .001). The positive value of the regression coefficient of the attribute information (ß = 0.6292, p < .001) indicates a conducive impact of a better information provision on the respondents' appraisal of the ridepooling systems.

The standard deviations of each coefficient, expect shift of departure are highly significant, indicating that these coefficients vary in the population. This implies that there is a substantial amount of heterogeneity in the preferences for the various service attributes [44].

4.3 Effect of trip purpose on choice behavior

The trip purpose had an impact on the choice behavior of the respondents as shown by the comparison of the two models in Table 2. The AIC for the model regarding the shopping scenario was 7569.833 whereas the AIC for the model concerning the doctor's appointment was 5930.466. Thus, the model for the shopping scenario results in less information loss than the model concerning the doctor's scenario.

As shown by a higher value of the coefficients, respondents that were confronted with the scenario doctor's appointment showed to be more attentive to the attributes travel time ($ß_{travel\ time:trip\ purpose\_doctor}$ = − 0.09108, p < .001) and shift of departure ($ß_{shift\ of\ departure:trip\ purpose\_doctor}$ = − 0.1048, p < .001) than respondents that were requested to imagine a shopping trip ($ß_{travel\ time}$: $_{trip\ purpose\_shopping}$ = − 0.0805, p < .001; $ß_{shift\ of\ departure:trip\ purpose\_shopping}$ = − 0.0978, p < .001). The interaction effect for trip purpose and travel time ($ß_{travel\ time:trip\ purpose}$ = − 0.0136, z = − 3.008, p = .002), as well as trip purpose and shift of departure was significant ($ß_{departure\ time:trip\ purpose}$ = − 0.0252, z = − 5.4067, p < .001). Furthermore, respondents that envisioned a doctor's appointment as trip purpose were more sensitive to an increase in walking distance to the pick-up point ($ß_{walking\ distance:trip\ purpose\_doctor} = -0.0031$, $p < .001$, $ß_{walking\ distance:trip\ purpose\_shopping} = -0.0026$, $p < .001$). The interaction effect was significant ($ß_{walking\ distance:trip\ purpose} = 0.0009$, $z = 4.535$, $p < .001$). The interaction terms concerning trip purpose and fare ($ß_{fare:trip\ purpose} = 0.0001$, $z = 0.2301$, $p = .818$) as well as trip purpose and booking time ($ß_{booking\ time:trip\ purpose} = -0.0014$, $z = -0.3885$, $p = .698$) and trip purpose and information ($ß_{information:trip\ purpose} = -0.057$, $z = -1.211$, $p = .226$) were not significant. Thus, no effect of trip purpose on the attributes fare, booking time and information was proven.

4.4 Willingness to pay estimation

The willingness to pay (WTP) for each attribute was calculated by estimating the ratio of the attribute's coefficient to the price coefficient [41]. Table 5 compares the WTP of the five attributes regarding the trip purpose. As shown here, the respondents' willingness to pay for an improvement in the quality of service differed depending on the trip purpose. Respondents that pictured the doctor's appointment are willing to pay 12 cent extra for a pick up point that is 100 m closer compared to a WTP of 9 cent per 100 m for respondents that pictured the shopping scenario. Respondents of both groups showed a great willingness to pay for a smaller shift of departure with 3.47 cent/min for the shopping trip and 5.52 cent/min for the trip to a doctor's appointment. The high importance of the attribute travel time for the participants in the doctor's scenario is reflected by a higher WTP for a reduction in travel time (4.80 cent/min) compared to the shopping trip (2.86 cent/min). Respondents further showed great willingness to pay for receiving more information on the ridepooling's trip details with only slight differences between the two trip purposes (20.16 cent/level for the shopping scenario and 21.28 cent/level for the doctor's appointment).

5 Discussion

5.1 Summary and interpretation of findings

This research was conducted in order to fill the research gap with regard to the limited empirical findings concerning travelers' preferences and needs related to ridepooling service concepts. The study builds upon and extents the recent study of König et al. [13] by broadening the focus and applying a regression modelling approach. Furthermore, the study adds onto the prior study by calculating willingness to pay values.

To conclude, all of the six service attributes proved to affect the respondents' appraisal of the ridepooling system. The model reveals that low fares, a small shift of departure and much information played a major role in the perceived utility of ridepooling services. The importance of a shift of departure further increases when the trip purpose was a fixed doctor's appointment. The model reveals that the utility of the ridepooling system decreases if the value of the service attributes increases, except the attribute information provision. The provision of more detailed information on the ride could thus be used to compensate the effect of a longer travel time or a higher shift of departure among others.

The attribute *fare* revealed a strong impact on the respondents' choice. Apparently, travelers attach high importance to low fares, thus confirming findings in the field of ridesharing that show cost savings to be one of the most influential attributes for using ridesharing [45]. The results are further in line with the findings of König et al. [13] that proved the high importance of price for urban residents' appraisal of ridepooling systems. The trip purpose had no significant effect on the respondents' appraisal of the attribute fare.

The importance of the service characteristic *walking distance* to access point was emphasized before in research concerning carpooling [46]. Accordingly, respondents showed a high willingness to pay for a gain in comfort due to a reduction of walking distance to the pick-up point. The results thus underline the relevance of a door-to-door service which can be a unique selling point of ridepooling services in comparison to public transport serving bus stops. The survey participants' willingness to pay for a reduction in walking distance was especially high when picturing a doctor's appointment. This finding is comprehensible in the light of the possible physical constraints that might be experienced when having a doctor's appointment.

The findings imply a high time sensitivity of respondents. A prolongation of the *travel time* due to the access and egress of fellow travelers was seen especially critical by respondents that were asked to picture a doctor's appointment as trip purpose as shown by a high willingness to pay for a reduction in travel time. The

Table 5 Willingness to pay (WTP) estimation of the five non-monetary attributes according to trip purpose

		Attribute				
		Walking distance (cent/m)	Time of booking (cent/min)	Shift of departure (cent/min)	Travel time (cent/min)	Information provision (cent/level)
Trip purpose	Shopping	0.09	0.60	3.47	2.86	20.16
	Doctor	0.16	0.47	5.52	4.80	21.28

findings underline the relevance of a fast ridepooling service, indicating that passengers would react very sensitive to long detours and would be willing to pay an extra amount of money in order to arrive punctually at appointments. In order to gain a wider acceptance of the flexible service concept of ridepooling systems further research should thus address the question which extent of roundabout way is acceptable depending on trip purpose and sociodemographic characteristics among others. Furthermore the finding underlines the relevance of a comprehensible real-time information provision to enhance service transparency and travelers' perception of control since the negative appraisal of a prolongation of travel time due to roundabout ways might be linked to an information deficit and a lack of traceability.

The service characteristic *time of booking* did as well affect the respondents' appraisal. It was shown that travelers value on-demand booking and are willing to pay for reducing the lead time of bookings. The analysis of interaction effects found no significant effect of trip purpose on the respondents' appraisal of the service attribute booking time.

The study further stressed the importance of the attribute *information* for the respondents' appraisal of the system. Since the flexibility and dynamic of the service concept are system inherent features of ridepooling services the need for a comprehensive information provision about the current trip increases compared to fixed scheduled public transport. It is likely to assume that an extensive information provision increases predictability of the service and thus enhance travelers' certainty and perceived control. Future research should examine the quality and quantity of information necessary to inform travelers about the operational concept in general as well as details of the current ride (e.g. route, arrival time, number of passengers boarding the vehicle).

Respondents seem to be highly sensitive to *shifts of departure* of the ridepooling systems that are caused by the previously entry or exit of other passengers. Shift of departure revealed a significant impact on the respondents' choice behavior in a way that the utility of a ridepooling service decreases if the departure time was postponed. Accordingly, they expressed a high willingness to pay for avoiding shifts of departure time. Further, a shift of departure seems to be of particular relevance when having a fixed appointment as indicated by the high WTP for a reduction in the extent of a shift of departure for the participants introduced to the doctor's scenario. Yet, timely flexibility is an inherent system characteristic of ridepooling schemes. Thus, a shift of departure and a detour are no exceptional cases of ridepooling operation but represent a usual case. Therefore, comprehensive explanations and information on the operational concept can be seen as a critical part for the users' acceptance of the ridepooling system. Furthermore, travelers should be informed preferably on time about changes of the departure or arrival of the transport system, once again underlining the importance of the attribute *information*. If ridepooling systems do not provide sufficient real-time information on the trip details, especially on the shift of departure and arrival a low acceptance of the innovative mobility form will be the result. In particular, travelers' willingness to use ridepooling systems for trips with a fixed date, like a job meeting, would presumably be low if the shift of departure and arrival would be too large. Thus, if ridepooling systems are expected to be used for a great variety of trip purposes extensive research on the timely and spatial dynamics of the service as well as the provision of information to facilitate the understanding and acceptance is needed.

To sum up, the results demonstrate that the credo "people will always favor the fastest transport mode unless it is more expensive than others" ([47], p. 1) is not necessarily applicable to the field of ridepooling services. Instead, travelers proved to be willing to pay for an improvement of service quality in terms of a shorter walk, an on-demand booking or a limitation of detour. The interpretation of the results implies that results regarding bus public transport cannot be simply transferred to the field of ridepooling but comprehensive research is needed in order to examine travelers' appraisal of ridepooling schemes.

5.2 Limitations and further research needs

It must be noted that the power of a Discrete Choice Experiment heavily relies on the selection of the attributes and levels. It is reasonable to assume that the extensive literature review and the focus group reduced the risk of an incorrect selection of attributes. Yet, it should be noted that the selection of attributes and their levels affected the model and the inclusion of further attributes, like attributes concerning the in-vehicle environment would possibly affect the model. Accordingly, the inclusion of sociodemographic variables like age or income would most likely influence the effects of the attributes on the travelers' appraisal of the ridepooling service. The authors thus see an important need for studying the effects of sociodemographic characteristics on the travelers' appraisal of ridepooling service characteristics.

Furthermore, it should be emphasized that the scope of the findings is limited to the chosen scenarios. The results described are thus restricted to the two trip purposes concerning a doctor's visit and a shopping trip in an urban setting. Further research could assess whether the findings are transferable to other trip types, like regular commuting trips. Presumably, the trip purposes will have a strong impact on the model and the willingness to pay.

Undoubtedly, the representativeness of the online survey participants must be questioned. A common limitation of online surveys lies in the self-selection of participants. To name one bias, the sample consisted of a lower share of participants that are aged above 65 years (16.6%) than in the German population (21% in 2016 according to the [48]). Furthermore the sample consisted of a higher share of well-educated people than the overall German population. For example, 53.7% of the respondents held an academic degree whereas the share in the German population is 16.5% [49]. The presented results thus cannot be simply inferred to the population but should be interpreted within the scope of the study's context and under consideration of the specific characteristics of the sample. The results need further validation in real-world experiments and field studies. Besides the analysis of sociodemographic characteristics of the respondents on the appraisal of the ridepooling's service attributes, the authors recommend modelling the effect of mobility behaviour and routines as well as prior conditions, like car ownership in further studies since habits have proven to play an important role for decision making and transport choices [12].

Since the description of the service concept and the attributes is seen as a critical part of the study as respondents need to understand the meaning of the attributes for assessing them, online surveys face the challenge of adequately imparting knowledge and gaining understanding. It is questionable if all participants understood the service concept of ridepooling and the description of the service attributes. For this reason, over 20% of the respondents were excluded from data analysis because of reading the introduction pages to fast. Yet, the study did not check whether the respondents really understood the meaning of the attributes. For instance, it is not possible to make a statement on the question whether the respondents understood the meaning of the attributes *booking time* and *shift of departure* as those are not common service characteristics of regular public transport modes that operate based on fixed lines and schedules.

5.3 Recommendations for public transport operators and transport authorities

Based on the findings, several theses can be derived that aim to adapt ridepooling service concepts to the needs of the travelers and thus might contribute to a more favorable appraisal of the transport system. Hence, when planning to launch a new ridepooling system the following recommendations should be considered in order to create and operate a ridepooling system that takes travelers' requirements into account.

- Overall travel time should be kept short by defining a maximum detour factor caused by roundabout ways.
- If possible, offer a door-to-door service to minimize walking distance to the pick-up point.
- Exploit opportunities based on digitalization to provide real-time booking opportunities that enable on demand mobility rather than long lead times for bookings.
- Shifts of departure time and changes in travel time are system inherent characteristics of ridepooling concepts and should be communicated as such to the users to ensure user acceptance.
- Travelers should be informed on time about changes in the departure or arrival of the ridepooling system using digital real time information systems on board and in a mobile application to avoid mistrust and disappointment about the ridepooling system.
- Avoid shifts of departure time shortly before the start of the ride by *freezing* the time window for bookings several minutes before the execution of a ride.
- The price could be adapted to the service quality of the offered ride in terms of low walking distance and few roundabout ways among others.
- Provide the possibility for the user to limit the maximum detour, respectively the latest time of arrival to ensure the timely meeting of appointments.
- Provide a customizable booking app that enables the configuration of individual preferences, e.g. the quantity of information provided about the trip.

6 Conclusions

In conclusion, the results of the study provide insight into the subjective relevance of factors that affect the users' appraisal of digitalized ridepooling characteristics since findings concerning fixed-scheduled public transport cannot merely be transferred to ridepooling concepts due to their system inherent dynamic of service. The results of the Discrete Choice Experiment show that respondents prefer short walking distances and react sensitive to a prolongation of travel time. Furthermore, the overall utility value increases as more information is provided. The utility of a ridepooling service decreases if the departure time is postponed and the operation requires higher lead times for booking. As expected, trip purpose affected the choice behavior in a way that respondents assessed the service characteristics differently depending on the trip purpose. The results give guidance for the creation of a user-centered public transport system that meets the requirements of the prospective passengers and thus might contribute to the adoption of such shared digitalized transport systems. Further research should consider sociodemographic effects on the appraisal of the service attributes of ridepooling and consider further trip purposes and the possible interplay with sociodemographic characteristics.

Abbreviations

AIC : Akaike Information Criterion; DCE: Discrete Choice Experiment; DRT: demand-responsive transport; MMNL: Mixed Multinominal Logit; RUT: Random Utility Theory; WTP: Willingness to pay

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Authors' contributions

AK prepared the idea and the research gap, carried out the literature review and the focus group, designed and carried out the DCE and analyzed the results. JG contributed in designing the DCE, derived the recommendations and contributed in writing the article. Both authors read and approved the final manuscript.

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Availability of data and materials

The datasets collected and analyzed in the study are not publicly available because of some personal data included in database but are available from the corresponding author on reasonable request.

Competing interests

We have no conflicts of interest to disclose.
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Attachment B - Publication 2

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A.K. provided the research idea.
A.K. developed serious game method
J.W. created the game concept
N.K. programmed the serious game
J.W. programmed the game
A.K. designed / planned / executed the study
J.G. gave research assistance.
J.G. gave methodological advice.
A.K. conducted the data collection in the experiment.
A.K. analyzed the data
J.G. supported the data analysis.
A.K. wrote the manuscript.
J.G. contributed to writing and improving of the manuscript.
J.W. contributed to writing and improving of the manuscript.
N. K. contributed to writing and improving of the manuscript.
J.G. contributed to revising the manuscript.
A.K. supervised the project.
J.G. gave scientific advice / constructive feedback

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Introducing a mobility on demand system to prospective users with the help of a serious game

Alexandra König [a,*], Niels Kowala [b], Jan Wegener [a], Jan Grippenkoven [a]

[a] German Aerospace Center, Institute of Transportation Systems, Lilienthalplatz 7, 38108 Braunschweig, Germany
[b] Magdeburg-Stendal University of Applied Sciences, VRSafe, Germany

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ABSTRACT

Sustainable mobility concepts are challenged to create a positive users' attitude and a high willingness-to-use to be adopted and survive on the market. Prospective users must not merely be informed about the service but become involved and feel affected. The contribution introduces a digital learning game, a so called serious game, to improve players' knowledge, attitude and willingness to use mobility on demand systems (MODS). The goal of an evaluation study in a high school (N = 71) was to compare the serious game and an online research according to the proposed effects on knowledge, attitude and usage intention. The study demonstrates that pupils' level of knowledge about the operational concepts of MODS increased after playing the game and the retention rate was higher. Playing the game furthermore resulted in a more positive appraisal of MODS concerning their usefulness. No significant effect of the serious game on the later usage behaviour was found. The paper points out the benefits of a gamified approach for introducing mobility services to prospective users and derives recommendations for the application of gamified approaches to facilitate the adoption of new technology or services.

1. Introduction

1.1. Challenges in the introduction of mobility on demand systems

Today, digitalization and automatization enable a variety of additional degrees of freedom for the provision of mobility on demand (Savelberg et al., 2017). Thus, we are witnessing the rapid dissemination of new means transport and associated services, like e-scooters or ridehailing, driven by the users' requirements for flexible and on-demand mobility. The article focusses on one of these new transport services – mobility on demand services that use dynamic ridepooling algorithms to either replace or complement public transport systems in areas and times of low demand by adapting their routes to the actual demand (Mulley and Nelson, 2009). Mobility on demand systems services (MODS) are in large parts very different from fixed-scheduled public transport since they can be defined as “an intermediate form of public transport, somewhere between a regular service route that uses small low floor buses and variably routed, highly personalised transport services offered by taxis” (Brake et al., 2004; p. 324). It can be assumed that prospective users' knowledge about the operation concept and service model of MODS is limited if they have not made any experiences with the service. Thus, before starting to operate new MODS, it is a wise approach to study the factors that might facilitate their adoption as well as usage barriers that prevent people from using MODS systems (König and Grippenkoven, 2019a, 2019b). A study that investigated the reasons for the discontinuance of the MODS *Kutsuplus* in Helsinki revealed that the inhabitants' information lack concerning how to use the service and the lack of awareness about the service were the main reasons for not having used the service (Weckström et al., 2018). Accordingly, the authors recommend that “[…] marketing strategy should reflect the end user target group, and aim at education on how to use the service” (Weckström et al., 2018, p. 96). In a household survey to examine residents' perception of a local demand-responsive transport system (DRT) that are comparable to MODS, Nelson and Phonphitakchai (2012) found that respondents have a low level of knowledge about the places served by the DRT service and showed that respondents' negative appraisal of the service was linked to a misunderstanding of the underlying service concept. Accordingly, Beirão and Cabral (2007) figured out that missing or insufficient information are a relevant barrier for using public transport in a qualitative study. Accordingly, Laws (2009) points out “[…] some of the DRT schemes included were not achieving the expected usage levels because potential passengers did not fully understand who the service was for, what the service was for or how to use the service.” (Laws, 2009, p. 240).

It is assumed, that meeting the users' requirements to a high degree with a user-centered service concept of MODS is a necessary but not a sufficient

* Corresponding author.
E-mail addresses: alexandra.koenig@dlr.de, (A. König), niels.kowala@vrsafe.de, (N. Kowala), jan.wegener@dlr.de, (J. Wegener), jan.grippenkoven@dlr.de. (J. Grippenkoven).

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precondition to achieve a high users' acceptance and willingness to use the system (König et al., 2017). Creating awareness and a sufficient understanding in the target group appear to be a key factors for the success of a new transport system. Therefore, three major challenges have to be considered as an early part of an effective and sustainable adoption process of new MODS:

1. A challenge of *sufficient conceptual comprehension*: referring to the prospective users' awareness and understanding of the operation concept, especially the flexibility of MODS and the necessity of dynamic routing results. An insufficient provision of information about how to use the mobility service or the absence of a transparent and understandable information environment could result in a refusal of the mobility service (Finn et al., 2004).
2. A challenge of *favourable appraisal*: as the intention to perform the behaviour in question can primarily be predicted from a positive attitude towards the behaviour (Ajzen, 1991), achieving a favourable appraisal of the MOD system is a necessary precondition for its acceptance and subsequently adoption. Especially, the perceived usefulness of a transportation system contributes to a favourable appraisal of DRT systems as shown by König and Grippenkoven (2019a).
3. Third, a challenge of *acceptance*: referring to the finding that a favourable assessment of a system or service is a necessary but not a sufficient precondition for its adoption (Dethloff, 2004). Thus, the transition between the preactional and actional stages that mark the phase of behavioural intention (Bamberg, 2013) must be facilitated by an active willingness to use the service (Ambrosino et al., 2003). Hence, to encourage people and to provide strong incentives to try out and experience the new system is of great relevance for facilitating the adoption process. Finding effective solutions for supporting citizens' adoption of sustainable mobility behaviors is an important challenge of present day's research (Gabrielli et al., 2014).

To face the named challenges, MODS should be first of all introduced to the prospective users in a comprehensive manner since empirical evidence proves the necessity. Furthermore, the model of self-regulated behavioural change of Bamberg (2013) suggests that individuals at an early, predecisional stage should be a target of interventions for activating problem awareness and perceived personal responsibility (Bamberg, 2013). For achieving prospective users' favourable attitude towards MODS it seems necessary to increase its perceived usefulness by underlining the individual, societal and environmental benefit of the new concept. Traditional means of raising awareness and facilitating understanding and a favourable appraisal concerning new transport systems are the word of mouth (Laws, 2009), internet homepages (Moia, 2019), flyers and instructions at the bus stops (Landkreis Teltow-Fläming, 2010) or articles in the local newspapers (Neumann, 2018). Yet, to master the named challenges when introducing innovative mobility services, new interactive and digitally based approaches might be a beneficial way to bridge the gap between dissemination and adoption.

1.2. Game-based learning

Games have always been an important element of culture in human evolution and have been used since thousands of years as an interactive learning environment for competition, cooperation and skill acquisition among others (Kriz, 2003). So called *Serious Games* are characterized by "a thought-out educational purpose and are not intended to be played primarily for amusement" (Abt, 1970, p. 9). The term is often used interchangeably with *edutainment games*, *games for behavioural change* and *persuasive games* among others (Antle et al., 2014; Crookall, 2010). Serious games are mainly used for game-based learning, but also for other purposes such as to initiate behavioural change (Bogost, 2010). Serious games should be differentiated from simulations that display reality as precise as possible whereas serious games reduce the complexity of the reality in the game model and thus offer a higher number of degrees of freedom (Freese et al., 2019).

Several empirical studies from different research domains confirmed the effectiveness of game-based learning, compared with conventional instruction methods. The studies found higher retention rates concerning declarative knowledge and procedural knowledge and greater learners' interest in the topic when introduced to game-based learning methods (Randel et al., 1992; Sitzmann, 2011; Tennyson and Jorczak, 2008; Wouters et al., 2013). Gamified approaches as an umbrella term for serious games, gamification and simulation games among others proved to support knowledge acquisition and content understanding in different domains as shown in a literature review conducted by Connolly et al. (2012). Game-based learning was also found to support players' positive appraisal (Connolly et al., 2012) and to prompt behavioural change (Klimmt, 2009; Soekarjo and van Oostendorp, 2015).

The power of games for facilitating learning processes can be traced back to the fact that games base on the same features like effective learning environments – they are engaging, situated and problem-based, ensure the learners attention, provide continuous and immediate feedback and an appropriate level of challenge (Boyle et al., 2011; Shute, 2011). Well-designed serious games encourage players to interact with the game world, experience mechanisms and concepts of complex socio-technical systems and thus become instrumental tools to support knowledge acquisition, help to change attitudes and encourage long-term behavioural change (Bogost, 2010; Hung and Van Eck, 2010).

1.3. Gamified approaches in transportation

Transportation systems are characterized by their high complexity and dynamic those are based on the large number of actors and interdependencies in socio-technical systems (De Bruijn and Herder, 2009; Mayer et al., 2010). Thus, interactive games are a promising approach to depict the complexity and dynamic of transportation systems. Accordingly, games and gamified approaches enjoy growing popularity in the last few years. Games in the transportation domain are mainly used as persuasive games to change players' mobility behaviour or transport mode choice, like the gamification approach *Streetlife*, that aims introduce new mobility services in pilot sites (Kelpin et al., 2016) or the game INSCINC that was developed to reduce peak demand in public transit (Pluntke and Prabhakar, 2013). There are also some examples of serious games in transport domain to facilitate learning about transport systems like the *Unilink Bus Game* (Yusoff, 2010) that aims to make international students of the University of Southampton familiar with the bus system. The simulation game of Wittowsky (2009) represents an example how games are used in transportation research to assess and quantify the effects of new technologies on the transportation system. Frequently, so called simulation games are used as a mean to discuss transport and infrastructure planning with transportation and land use experts or other stakeholders or to train stakeholders how to handle disruptions in the transportation network (Klemke et al., 2015). Another example is *SprintCity*, a multi-player game that is intended to be played with experts in the field of rail transportation (Duffhues et al., 2014). There is also a broad and growing branch of research assessing the potentials of gamification that is defined as the use of game element in other contexts, to incentivize behavioural changes towards sustainable mobility solution and mode shift (Kazhamiakin et al., 2015; Liyanage et al., 2019).

The review of gamified approaches in transportation research reveals a growing interest of science and practitioners in applying games for different purposes. Yet, these applications of gamified approaches often lack a systematic theoretical foundation and a comprehensive evaluation of their desired impacts and side effects. Furthermore, the literature review reveals a lack in empirical findings regarding the use of gamified approaches for facilitating the introduction of new mobility services, such as MODS.

1.4. A theoretical framework for the evaluation of game-based learning

Literature acknowledges the proposed positive effects of gamified approaches on learning, attitude or behaviour, yet, the empirical validation of its effectiveness is fragmented and sparse (Van der Kooij et al., 2015) and the “discourse has largely remained at a conceptual level” (Ritterfeld et al., 2009, p. 691).Whereas psychology and social science have a long tradition of developing evaluation tools and measures, only few validated tools exist for the assessment of play-specific experiences and its effects (Van der Kooij et al., 2015). As one possible approach the introduction of new MODS can be understood as the task to make users accept a new transport technology (Chen and Chao, 2011). Thus, Yusoff (2010) used the Technology Acceptance Model (TAM, Davis, 1989) to evaluate the serious game *Unilink Bus Game* that introduced international students to public transport in Southampton. The model describes two direct factors of an individual's attitude towards a product or service: the *perceived usefulness* and the *perceived ease of use* (Davis, 1989). The theory proposes a favourable attitude to be a direct antecedent of the behavioural intention to use a product or service which in turn is the only direct determinant of the actual use behaviour.

Another approach to evaluate the effectiveness of game-based learning comes from citizen participation that often use gamified approaches to involve citizen as games provide an interactive instrument to inform and involve citizens and asses their needs (e.g. De Lange, 2015; Meloni and Antunes, 2017). Civic engagement and participation in transport planning is based on the idea to think about citizens as planners rather than mere consumers and thus involve them in the co-creation of solutions for sustainable transportation (Sagaris, 2014). Yet, the effects of participation on the local transport plan process are rarely evaluated (Bickerstaff et al., 2002). The difficulty of measuring change process due to participation processes (Gebhardt et al., 2019) and the need to conduct evaluation studies are outlined in the existing literature (Rowe and Frewer, 2004). Approaches of citizen participation and gamified approaches share the common element of a highly complex research objective. The complexity of the research objective requires evaluation methods that give regard to this and consider the temporal course of the development and the adoption of ideas and innovation in the real-context. Kebritchi (2010) applied Roger's theory of Diffusion of Innovation (DoI) to the adoption of computer games (Rogers, 2003). The DoI is one of the most prominent theories concerning the distribution of technological innovations in society and empirically well established. The theory has also been applied to mobility research (Keller et al., 2018). The DoI theory appears useful for assessing the adoption process of a new mobility service. The theory is based on the premise that diffusion, is distributed over five stages, that might serve as a reasonable basis for user tests (Rogers, 2003). These stages are *knowledge*, *persuasion*, *decision*, *implementation* and *confirmation* and a preceding stage concerning *prior conditions* as social norms or experiences (Rogers, 2003). According to the theory, the individual adoption process of an innovation starts with the knowledge phase, where the individual is first exposed to an innovation, but has not made any experiences within the system. The knowledge phase is thus an essential prerequisite for the following phases of adoption. Rogers differentiates between three kinds of knowledge concerning an innovation: 1) awareness knowledge: the conscious perception of an innovation, 2) how-to-knowledge: knowledge about the functionality and manner of utilization and 3) principles knowledge: the understanding of subjacent processes and background information.

The study at hand integrates the theoretical frameworks of the Technology Acceptance Model and the Theory of Diffusion of Innovation to a research model as done before (Agag and El-Masry, 2016; Lee et al., 2011). As presented in Fig. 1, the DoI is expected to complement the rather condensed TAM with further determinants of the use behaviour. It is also expected that the integration of the two models better reflects the adoption process. The resulting research model is used for the evaluation of the effectiveness of a serious game for increasing the knowledge and conceptual understanding about mobility on demand systems and facilitating its positive appraisal as well as raising the usage intention.

1.5. Research aim of the paper

The paper at hand adapts a game-based learning approach for introducing mobility on demand systems to prospective users by addressing the challenges named of *sufficient conceptual comprehension, favourable appraisal* and *acceptance*. The named challenges are reflected by the proposed research model (Fig. 1) in a way that the knowledge phase addresses the challenge of sufficient conceptual comprehension, whereas the persuasion phase deals with the challenge of a favourable appraisal and the decision phase with the acceptance challenge respectively. More specifically, the paper presents the serious game *B.u.S.* (*Bürger unterrichten durch Spiele*, engl.: Teaching citizens through games) that was developed to enhance players' knowledge, attitude and subsequently behavioural intention for mobility on demand systems. The game's effectiveness as an experiential learning tool was assessed with the help of an experimental evaluation study. Even though the game was developed for different user groups aged from 10 to 99 years, the target group of the study were high school pupils as being aged between 15 and 24 years was found to be a key target group of DRT services in Australia in a literature review (Jain et al., 2017). Adding onto this, mobility on demand systems that often fail because of low usage rates as found by Enoch et al. (2006) for Great Britain might benefit from addressing the target group of children and teenagers as they

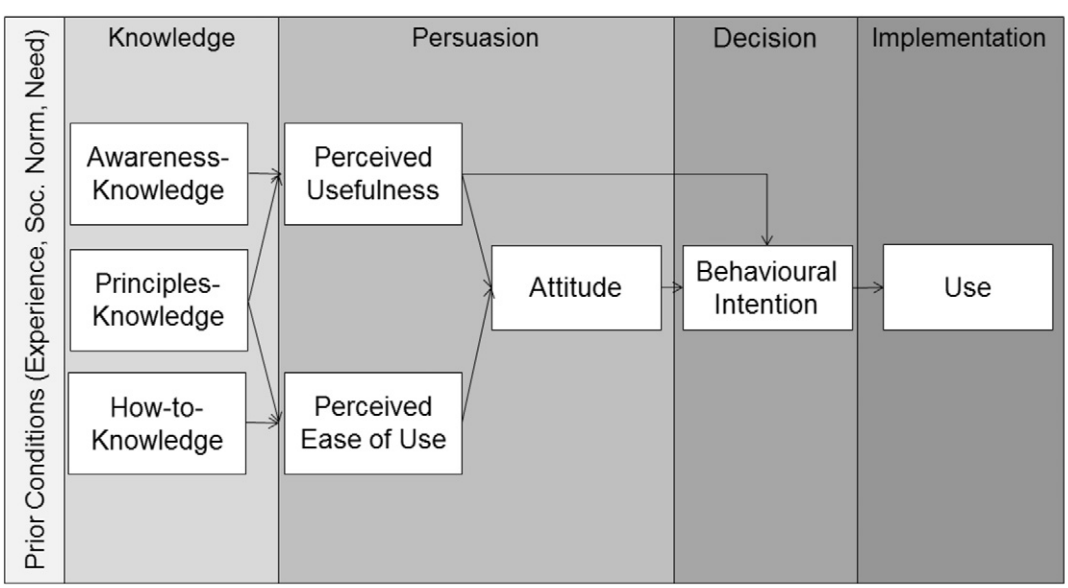

Fig. 1. Research model based on the Technology Acceptance Model (Davis, 1989) and Diffusion of Innovation (Rogers, 2003).

represent a relevant share on regular mobile persons. Pupils living in rural areas of Germany travel on average 9 km to school (Nobis and Kuhnimhof, 2018). In Germany, 8% of every trip is an accompanied way, mostly conducted by parents and their children (Nobis and Kuhnimhof, 2018). Reducing the number of accompanied trips is an ambitious goal towards more environmentally sustainable and self-determined mobility of adolescents. Another reason for focussing on teenagers as target group lies in the fact that the teenagers of today will be the grown-ups of tomorrow and will affect the transport system with their modal choices. Above this, targeting adolescents is seen as an effective strategy in einfluencing the attitudes and change processes of younger and older generations as young people are currently exerting mighty behavioural influence on their parents (Arthur D. Little and UITP, 2014).

2. Methods and materials

2.1. The serious game B.u.S.

The serious game *B.u.S.* was developed based on the *Contextual Design* approach by Holtzblatt et al. (2004) that is characterized by a systemic, user-centered and prototype based development process. *B.u.S.* was created and developed by an interdisciplinary team of two game designers, a psychologist, a human factors specialist and a computer scientist with the game engine *Unity Engine* (Unity Technologies, 2019). The game was developed based on an iterative process that included loops of testing and adjustments of early prototypes (Fig. 2). Usability tests were conducted during the design phase with the help of the methods of Thinking Aloud (Dumas, 2001) and a Heuristic Evaluation (Nielsen and Molich, 1990).

To meet the challenges of the introduction of new mobility services (Section 1.1) the mobile game *B.u.S.* was designed as single-player role game that puts the players in the position of a public traffic planner (König et al., 2017). Role-play games have proved to elicit empathic responses from player sas they uniting their goals with that of their protagonists and make the players reflect about the perspective of the role (Jacobs et al., 2017). Learning through role play was applied for different learning purposes and has shown to improve player's cognitive and emotional involvement (Colucci-Gray, 2004). With the help of the role-game, players were forced to adapt the role of a traffic planner and leave the egocentric perspective of users. Thereby, the player should experience the complete picture of the transport system. Bogost (2010)) uses the term *procedural rhetorics* for persuasion through rule-based representations and interactions rather than direct speech. In this way, the players were encouraged to experience the transport system according to the Exploratory Learning Model (De Freitas and Neumann, 2010). The players of *B.u.S.* thus explore a virtual city and the residents' mobility and operate a mobility on demand system that serves the mobility needs of different residents. The player's task is to route the MODS vehicles according to the actual needs of the travelers and pick them up at a variety of stops and transport them to their desired destinations. To reflect the complexity and heterogeneity of passengers' demands the game concept uses different colored figures that illustrate the desired destination of the travelers (Fig. 3). Furthermore, players are encouraged to meet the goal of an efficient and environmental friendly operation. It is supposed that the players are enabled to understand the logic of operational planning and become aware of the effects of traffic planning by routing the on-demand vehicle. Thereby the challenge of sufficient conceptual comprehension is addressed.

The game concept of *B.u.S.* is level-based with new and increasingly difficult mission goals that force the player to explore the actual game situation. At each level, the player is confronted with a challenge that can only be solved through goal-directed exploration of the simulated system. An evaluation screen provides feedback about how successful the player's solution was based on a rating with asterisks and textual description (Fig. 3, bottom). During game play immediate feedback about the MODS performance is given by dynamic bar charts that display the waiting time of travelers and the ecological friendliness of the service due to a low number of empty runs. Furthermore, feedback on the passenger's satisfaction according to low wait times is operationalized by using frown smileys as shown in Fig. 3. In order to demonstrate the differences between fixed-scheduled bus transport and MODS and to demonstrate the benefits of flexible routing, a public bus is introduced in level 4. The public bus serves fixed bus stops and operates in a fixed-scheduled manner. Players are encouraged to complement the public bus by demand-driven operation of the MODS and are expected to learn the differences of the operational concepts of both transport services by the direct comparison.

The players are expected to elicit a favourable appraisal of the new bus system, addressing the second challenge, by demonstrating the positive effects and benefits of MODS for the passengers, the transport company, the society and the environment as well. The experiential game approach encourages the player to actively deal with the new system and experience system functions and constraints. The active component of the game is meant to increase the player's willingness to use the new bus system, thus addressing the acceptance challenge. For transferring the acquired knowledge to the daily life and to improve the willingness to use the bus system an extensive debriefing was part of the gaming experience (Crookall, 2010).

2.2. Participants

The study's participants were pupils of 10th to 12th grade (N = 71) of a high school in Luckenwalde, a small town in Brandenburg, Germany. The location was chosen as an on demand system called *Rufbus* operates since 2010 in the study area (Landkreis Teltow-Fläming, 2010). Residents of the districts of Nuthe-Urstromtal can use the transport system every day from 05:30 to 21:30 and at the weekends from 08:30 to 21:30. The pupil were recruited with the help of the school administration. The evaluation study was conducted in three different clases that were teached by the same teacher to control for this variable. The experiment was performed during a regular class thus avoiding self-selection effects due to voluntary participation in the leisure time. Hence, it can be assumed that the participation was somehow mandatory.

Tthe mean age of the sample was 16.75 years ($SD = 1.07$). Gender was equally distributed among the sample (female = 36, 50.7%). Every

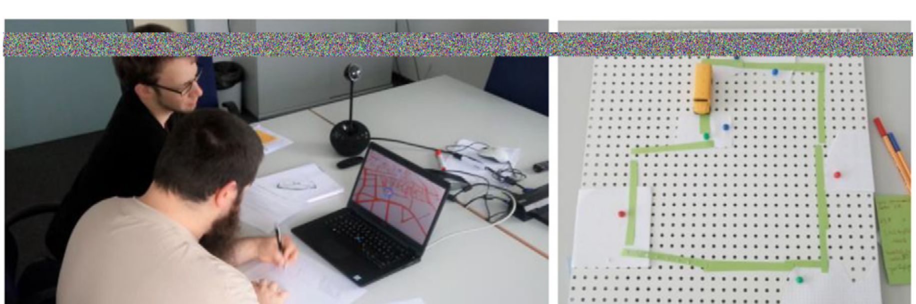

Fig. 2. Left: Heuristic evaluation of the game's usability. Right: Early prototype of the game.

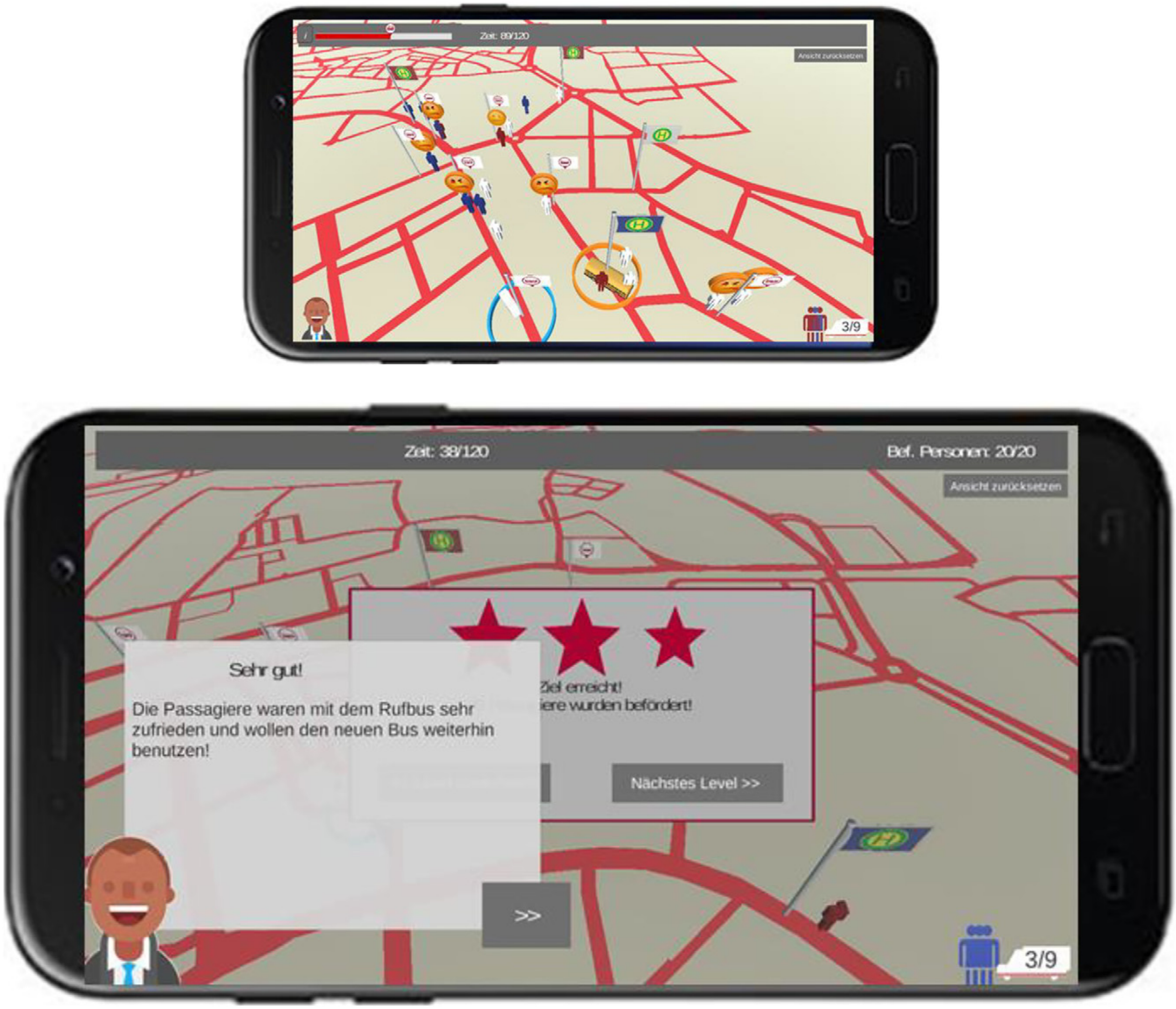

Fig. 3. Screenshots of the mobile game *B.u.S.* Top: Gaming situation at level 4 with an additional fixed-line service, Bottom: feedback site with evaluation screen.

participant stated to own a smartphone (100%) and 42.3% (n = 30) specified to own a tablet. The majority of the participants stated to be online for at least 60 min per day (91.5%, n = 65). Concerning their game play experiences, about three fourths of the participants specified to play games at least several times per week (76%, n = 54). Five participants stated to play no games (7.0%). The share of participants' game experiences was equally distributed among the two experimental groups. Concerning the most used transport mode for daily trips to school 43.7% (n = 31) specified bus transport, bike by another 29.6% (n = 21). The private car was used as a driver by 14.1% (n = 10) and as car passenger by another 5.6% (n = 4) as most frequently used means of transport for school trips. Walking was specified by 7.0% (n = 5) to be the most frequent mode for trips to school.

2.3. Material

The study was accompanied by three questionnaires: 1) a pre-test, 2) a post-test and 3) a second post-test. Each questionnaire based on the same questions regarding the knowledge about MODS, attitudes towards MODS concerning the perceived reliability, price, speed and environmentally friendliness adapted from Chen and Chao (2011). For measuring the TAM constructs Perceived Ease of Use and Perceived Usefulness, the items from the were adapted to the context of DRT. Additionally, the pre-test consisted of questions regarding sociodemographic characteristics, mobility behaviour and prior experiences with the local MODS *Rufbus*. The post-test included questions concerning the game and online research experience, respectively. The second post-test consisted of additional questions regarding the usage of the *Rufbus* during the last weeks.

For the questionnaires, 5-point likert scale questions and open questions were used.

2.4. Study design and procedure

The study design entails a classical repeated measures design with a control group (Hainey, 2010). The first post-test was conducted directly after the intervention. To investigate the knowledge retention over a medium period of time a second post-test was conducted four weeks after the game session (Catalano et al., 2014). The experimental design of the evaluation study is shown in Fig. 4.

After a written pre-test (T1), the participants were randomly assigned to either the experimental group or the control group with the help of drawing sweets from a *Celebrations*® box. In a separate classroom, the experimental group was introduced to the serious game *B.u.S.* and played the game for 15 min on smartphones or tablet computers (Fig. 5). Subsequently, they did a 5-min written reflection on the game and what they have learned since the reflection and debriefing phase is seen as a very important component of gamified learning to facilitate the knowledge transfer

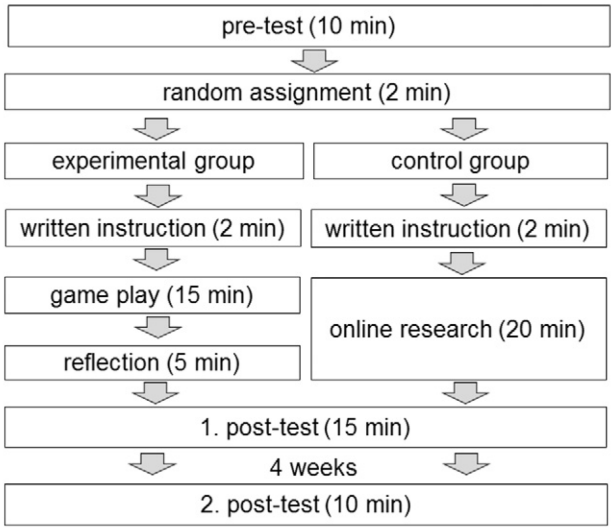

Fig. 4. Experimental design.

from the game to the real world (Crookall, 2010). Three open questions were used to facilitate the reflection (*Shortly describe your task in the game. Which experiences have you gained by playing the game? Which is your main lesson learned after playing the game?*). In the meantime, the control group was encouraged to inform themselves about mobility on demand systems with the help of an online research with tablet computers or smartphones (20 min). The online research was chosen as a comparative measure to the game as they share relevant characteristics as the medium and the familiarity for the target group. Furthermore, the online information-seeking is a very common way of adolescents to obtain information (Micheli, 2015). After the game or respectively the online research session, the participants completed the post-test questionnaire (T2). After four weeks, they were handed the second post-test questionnaires (T3).

3. Results

In the following section, the study findings are presented according to the stages of the research model (Fig. 1). First, the developed game is assessed due to its perceived difficulty and fun as a mean for plausibility check and a control for the internal validity. Game's difficulty was assessed as medium difficult (M = 2.86, 1 = very difficult; 5 = very easy), showing a wide span of players' assessment (SD = 2.3). Four participants (n = 10.8%) experienced concrete difficulties in the handling of the game (too small textual descriptions and unawareness about the possibility to move the city map). The majority of the players played the game up to level 4 of 6. The analysis of the question regarding the experience of fun during the game play showed that participants enjoyed playing the game and experienced fun (M = 3.94, SD = 0.94,1 = very little fun; 5 = a lot of fun).

For the statistical analysis, a repeated measurement analysis of variance (ANOVA) was used to analyze the differences among the group means between the different points in time. Basically, ANOVA assesses whether or not two or more means are equal and is relatively robust against violations of its assumptions (Field, 2009). ANOVA are applied when more than two groups are regarded. For the analysis of the intervention effect between the control group and the experimental group, *t*-tests were used (Field, 2009).

3.1. Prior conditions

Prior conditions form a preceding stage of the 5-stages research model and comprise of previous experiences and social norms (Rogers, 2003). Concerning their previous experiences with the local MODS, the share of pupils that have used the *Rufbus* before was small with 7.0% (n = 5) of respondents using the transport system less than once a month and only one person using the service about once a week (1.4%). In contrast, 91.5% of respondents specified that they had not used the service before (n = 65). As reasons for non-usage, respondents stated *no need* (n = 33), *ignorance about the service* (n = 32), *predominant advantages of a private car* (n = 3) and *unclear functionality* (n = 2) as well as *costs* (n = 1) and *constraints of the operation time* (n = 1).

Social norms were assessed with the help of three items. For the first item concerning the image of MODS a significant effect of *time* was shown. Both groups showed an improvement in the assessment of the image of MODS from T1 to T2 ($F(1,67) = 6.130$, $p = .016$, partial $\eta^2 = 0.084$, $d = 0.3$). At T2, the friends' appraisal of the *Rufbus* (*I believe my friends would encourage me to use the Rufbus more often*) was more favourable than at T1 ($F(1,66) = 7.313$, $p = .009$, partial $\eta^2 = 0.100$, $d = 0.33$). The beneficial effect of the interventions was not found for the item concerning the family's appraisal of the *Rufbus* (*I believe my family would encourage me to use the Rufbus more often*, $F(1,67) = 0.075$, $p = .785$, partial $\eta^2 = 0.001$, $d = 0.03$). The analysis revealed no effect of the learning medium on the three items concerning social norms.

3.2. Knowledge stage

3.2.1. Awareness-knowledge

The pretest revealed that more than half of the study's participants had not heard about the local demand-responsive transport service before (57.7%, n = 41), showing that the pupils' awareness for the transport

Fig. 5. Experimental setting of the evaluation study.

service was rather low. After the intervention, all of the participants stated to have heard about the service.

3.2.2. Principles knowledge

For the assessment of the principles knowledge as a construct to measure the understanding of subjacent processes and background information an open question was analyzed: *Which are the differences between fixed-scheduled bus transport and demand-responsive bus transport*? The number of named correct differences (e.g. operates without fixed schedule, requires additional fee) was analyzed as a measure for the principles knowledge.

An ANOVA with repeated measurements showed a significant main effect of the factor *time* regarding the principles knowledge ($F(2,78) = 11.025, p < .001$, partial $\eta^2 = 0.260, d = 0.593$). Post-hoc tests revealed that the respondents' principles knowledge significantly increased between T1 ($M_{T1} = 0.96$, $SD_{T1} = 1.006$) and T2 ($M_{T2} = 1.85$, $SD_{T2} = 1.129$, $t(70) = -6.221$, $p < .001$, $d = 0.597$) and between T2 and T3 ($M_{T3} = 1.475$, $SD_{T3} = 0.877$, $t(39) = -2.876$, $p = .006$, $d = 0.418$) as shown in Fig. 6. Concerning the effect of the learning medium, the analysis revealed that in T2, the amount of the named differences did not significantly differ between the two experimental groups ($M_{T2\_serious\_game} = 1.95$, $SD_{T2\_serious\_game} = 1.25$; $M_{T2\_online\_research} = 1.74$, $SD_{T2\_online\_research} = 0.99$; $t(69) = 0.783$, $p = .436$). As shown in a *t*-test, the retention rate significantly differed between the two groups after four weeks in T3 ($t(39) = 2.098$, $p = .043$, $d = 0.32$) in a way that the group that had played the game retained more knowledge about the differences between the bus concepts ($M_{T2\_serious\_game} = 1.73$, $SD_{T2\_serious\_game} = 0.63$) than the control group ($M_{T2\_online\_research} = 1.17$, $SD_{T2\_online\_research} = 1.04$).

3.2.3. How-to-knowledge

Looking at the participants' knowledge about the functionality and the booking process of demand-responsive transport (*Which details do you know about the functionality of demand-responsive transport?*), the analysis revealed an effect of time but no effect of the learning medium. The number of named correct details (e.g. booked in advance) was analyzed as a measure for the how-to-knowledge.

An ANOVA with repeated measurements showed a significant main effect of the factor *time* regarding the principles knowledge ($F(2,78) = 22.112, p < .001$, partial $\eta^2 = 0.362, d = 0.753$). Post-hoc tests revealed that the how-to-knowledge significantly increased between T1 ($M_{T1} = 1.25$, $SD_{T1} = 1.431$) and T2 ($M_{T2} = 2.65$, $SD_{T2} = 1.435$, $t(70) = -6.613$, $p < .001$, $d = 0.617$) and between T2 and T3 ($M_{T3} = 2.00$, $SD_{T3} = 1.177$, $t(39) = -4.118$, $p < .001$, $d = 0.550$). The amount of the named characteristics of MODS slightly failed to reach significance when compared between the two experimental groups in T2 ($M_{T2\_serious\_game} = 2.35$, $SD_{T2\_serious\_game} = 1.46$; $M_{T2\_online\_research} = 2.97$, $S_{T2\_online\_research} = 1.36$; $t(69) = -1.847$, $p = .069$, $d = 0.22$). After four weeks (T3), the amount of characteristics decreased in both groups ($F(1,38) = 17.024, p < .001$, partial $\eta^2 = 0.309, d = 0.67$). No significant effect of the learning medium on the retention rate in T3 was shown in a *t*-test ($t(38) = -1.083, p = .286$) (Fig. 7).

The effects of an increase of knowledge about the concept of demand-responsive transport are in line with the subjective perception of the participants that assessed their knowledge about MODS (*How good is your knowledge about the functionality and the booking process of mobility on demand systems*?). An ANOVA with repeated measurements showed a significant main effect of the factor time regarding the self-assessed knowledge ($F(2,78) = 48.918, p < .001$, partial $\eta^2 = 0.556, d = 1.12$). Post-hoc tests revealed that the respondents' self-assessed knowledge significantly increased between T1 ($M_{T1} = 1.83$, $SD_{T1} = 1.23$) and T2 ($M_{T2} = 3.52$, $SD_{T2} = 0.984$, $t(70) = -11.403, p < .001, d = 0.806$) but no significant effect was found between T2 and T3 ($M_{T3} = 3.68$, $SD_{T3} = 0.859$, $t(39) = 0.408$, $p = .686$). In line with the results concerning the participants knowledge about the functionality of MODS that found a marginally significant difference in the amount of named facts between the two experimental groups, the control group assessed their knowledge better in T2 ($M_{T2\_online\_research} = 3.91$, $S_{T2\_online\_research} = 0.62$) than the experimental group ($M_{T2\_serious\_game} = 3.16$, $SD_{T2\_serious\_game} = 1.12$; $t(69) = -3.449$, $p = .001$, $d = 0.38$).

3.3. Stage of persuasion

3.3.1. Perceived usefulness

For the assessment of the Perceived Usefulness a new variable was computed that reflected the mean Perceived Usefulness over the five items. Internal consistence was acceptable as shown by a Cronbach's

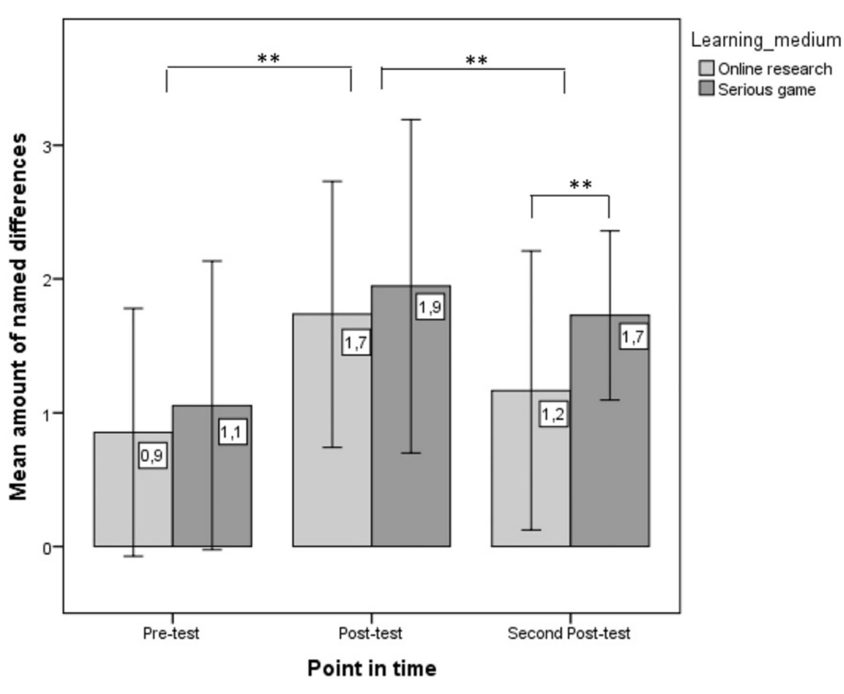

Fig. 6. Mean amount of named differences between bus concepts according to learning medium and time of measurement. Whiskers represent ±1 standard deviation. ** $p < .05$.

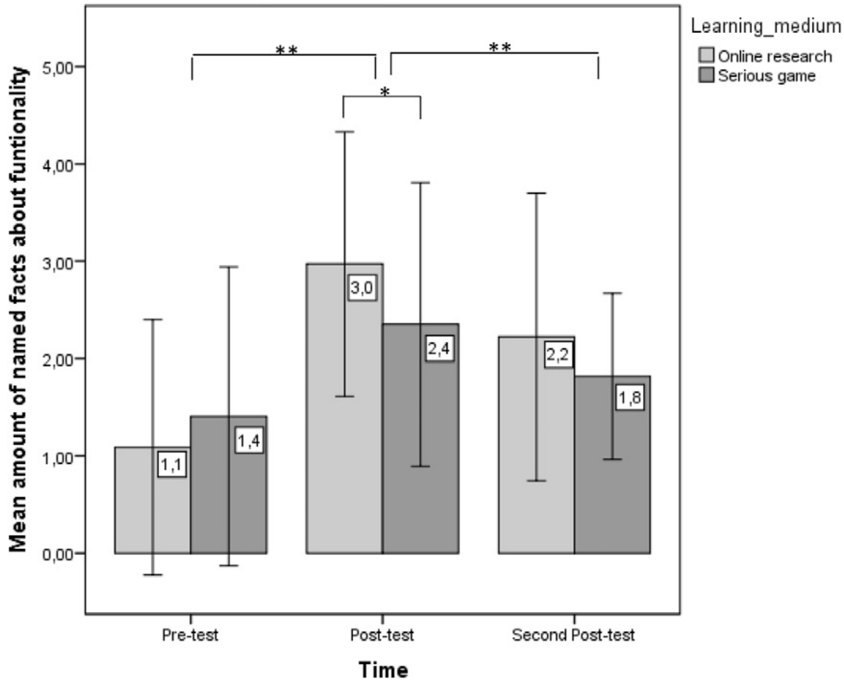

Fig. 7. Mean amount of named facts about the functionality and booking process of demand-responsive transport according to learning medium and time of measurement. Whiskers represent ±1 standard deviation. * $p < .1$, ** $p < .05$.

alpha of $\alpha = 0.64$. An ANOVA with repeated measurements showed a significant main effect of the factor *time* regarding the mean Perceived Usefulness ($F(2,72) = 7.636, p = .001$, partial $\eta^2 = 0.175$, $d = 0.461$). Post-hoc tests revealed that the mean Perceived Usefulness significantly increased between T1 ($M_{T1} = 2.85$, $SD_{T1} = 0.650$) and T2 ($M_{T2} = 3.06$, $SD_{T2} = 0.67$, $t(70) = -2.734$, $p = .008$, $d = 0.31$) and significantly decreased between T2 and T3 ($M_{T3} = 2.59$, $SD_{T2} = 0.65$, $t(36) = -4.007$, $p < .001$, $d = 0.555$) as shown in Fig. 8. The mean perceived usefulness was marginally higher in T3 for experimental group ($M = 2.75$, $SD = 0.66$) than for the control group ($M = 2.39$, $SD = 0.60$, $t(35) = 1.712$, $p = .096$, d = 0.278).

Looking at the usefulness items separately, significant effects of the learning medium revealed. More specifically, the Perceived Usefulness for transport agencies was assessed higher in T3 by participants that played the game ($M = 3.52$, $SD = 0.81$) than by participants that dealt with the online research ($M = 2.75$, $SD = 1.07$; $t_{T3}(35) = 2.509$

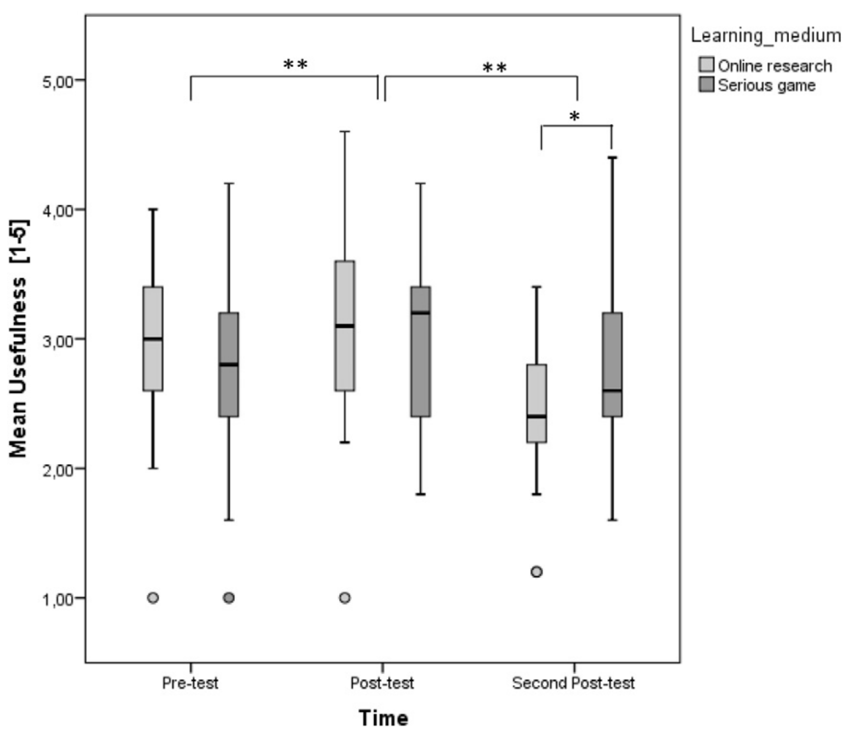

Fig. 8. Usefulness assessment according to learning medium and time of measurement. Whiskers represent 95% confidence interval. Note. * $p < .1$, ** $p < .05$.

$p = .017$, $d = 0.39$). Playing the game also was linked to a higher Perceived Usefulness concerning the improvement of respondents' personal mobility in T3 ($M = 2.19$, $SD = 1.33$) compared to the online research ($M = 1.44$, $SD = 0.63$; $t(35) = 2.092$, $p = .044$, $d = 0.33$). In T2 and T3, the control group assessed the benefits for the environment better ($M_{T2} = 3.47$, $SD_{T2} = 1.19$; $M_{T3} = 3.13$, $SD_{T3} = 1.15$) than the experimental group ($M_{T2} = 2.76$, $SD_{T2} = 1.09$; $M_{T3} = 2.48$, $SD_{T3} = 0.93$; $t_{T2}(69) = -2.642$, $p = .010$, $d = 0.30$; $t_{T3}(35) = -1.902$, $p = .065$, $d = 0.30$).

3.3.2. Perceived ease of use

In line with the process concerning the Perceived Usefulness, a new variable was computed, reflecting the mean value of the three Ease of Use items. Internal consistence of the construct was acceptable as shown by a Cronbach's alpha of $\alpha = 0.70$. An repeated measures ANOVA showed no significant effect of time regarding the mean perceived Ease of Use ($F(2,72) = 2.193$, $p = .119$, partial $\eta^2 = 0.057$). *t*-Tests revealed no effect of the learning medium on the mean Ease of Use in T2($t_{T2}(69) = 0.605$, $p = .547$) or T3 ($t_{T2}(35) = -1.188$, $p = .243$). Accordingly, further analysis revealed no significant effects of the time or the interaction of time and the learning medium regarding the separate items of the Ease of Use construct.

3.3.3. Attitude

The respondents' attitude towards MODS was measured and analyzed concerning the perceived reliability, price, speed and environmentally friendliness of MODS.

The analysis revealed no significant time effect in perceived *reliability* ($F(2,66) = 1.763$, $p = .180$, partial $\eta^2 = 0.051$), *price* ($F(2,66) = 0.126$, $p = .882$, partial $\eta^2 = 0.004$), *speed* ($F(2,70) = 1.483$, $p = .234$, partial $\eta^2 = 0.0041$) but for *environmentally friendliness* ($F(2,70) = 3.759$, $p = .028$, partial $\eta^2 = 0.097$, $d = 0.328$). A post-hoc analysis showed that the perceived environmentally friendliness of MODS marginal significantly increased between T1 ($M_{T1} = 2.85$, $SD_{T1} = 0.919$) and T2 ($M_{T2} = 3.0$, $SD_{T2} = 1.12$, $t(67) = -1.687$, $p = .096$, $d = 0.202$) and significant decreased in T3 ($M_{T3} = 2.68$, $SD_{T3} = 1.00$; $t(36) = -2.435$, $p = .020$, $d = 0.376$). The comparison of the learning medium revealed a significant effects on participants attitude concerning the assessment of it's environmentally friendliness. At T2, the control group assessed the environmentally friendliness of MODS significantly better ($M_{T2} = 3.44$, $SD_{T2} = 0.93$) than the experimental group ($M_{T2} = 2.60$, $SD_{T2} = 1.14$; $t(67) = -3.352$, $p = .001$, $d = 0.38$).

The participants' attitude towards MODS was also assessed with the help of a more qualitative open question: *Which three words come to your mind first, when you think about mobility on demand systems?* The associations were analyzed according to their valence. Three clusters were built according to the valence of the attributed terms: 1) *positive* (p.e. comfortable, punctual), *negative* (p.e. unreliable, awkward) and *neutral* (p.e. bus, transport). As shown in Fig. 9, the percentage of neutral attributions decreased in both groups between T1 and T2. For the control group, the share of neutral attributions was 79.6% in T1 and 59.8% in T2 as well as 69.1% and 54.5% for the experimental group respectively. In contrast, the number of positive as well as negative attributions concerning MODS increased between T1 and T2. Synoptically, after the intervention the participants' attitude concerning the service becomes more valent. This increase in valence of the appraisal happens in both directions – towards a more positive as well as a more negative appraisal. The most common negative attributions of the participants that have played the game in T2 were “intricate” (n = 3), “stressful” (n = 2) and “waiting” (n = 2), whereas most often named positive associations were “fast” (n = 11) and “flexible” (n = 8). In contrast, the control group mentioned “environmentally friendly” (n = 7) and “fast” (n = 6) as positive associations and “expensive” (n = 3) as negative associations concerning MODS.

3.4. Decision stage

Respondents' Behavioural Intention to use was measured with the help of two items:1) How likely is it that you will use the Rufbus within the next four weeks? and 2) I believe I will use the Rufbus within the next three months. An ANOVA with repeated measurements found a significant effect of time on the perceived likelihood to use the local MODS within the next four weeks in a way that the willingness increased after the intervention ($M_{T1} = 0.916$, $SD_{T1} = 1.763$, $M_{T2} = 1.43$, $SD_{T2} = 0.953$, $F(1,70) = 4.534$, $p = .037$, partial $\eta^2 = 0.061$, d = 0.477). No significant differences

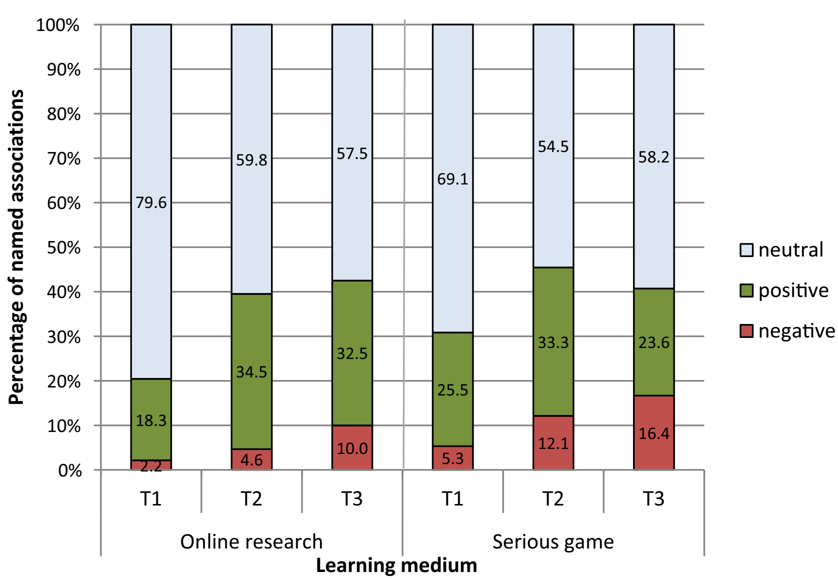

Fig. 9. Distribution of negative, positive and neutral assessed words according to time and learning medium. Note. negative: pointless, to wait, detours, money, expensive, unreasonable, unpunctual, stressful, crowded, environmental pollution, insufficient, infrequently available, complicated, unreliable, insecure; positive: spontaneous, cheap, flexible, convenient, economical, contemporary, environmentally friendly, punctual, comfortable, reliable, smart, reasonable, uncomplicated; neutral: to call, bus, transport, telephone, App, taxi, individual, small, bus driver, to pick sb. up, retired persons, elderly, to walk, to ride, seat, share, to book, booking, private, school, excursion, front door, reservation, road, mobile phone, hitchhiker, different, to plan, stop, on demand, Uber, traffic, alternative transport mode, car, mobility, independent, persons, unknown, at the weekend, route planning, public, village, organisation, Teltow-Fläming.

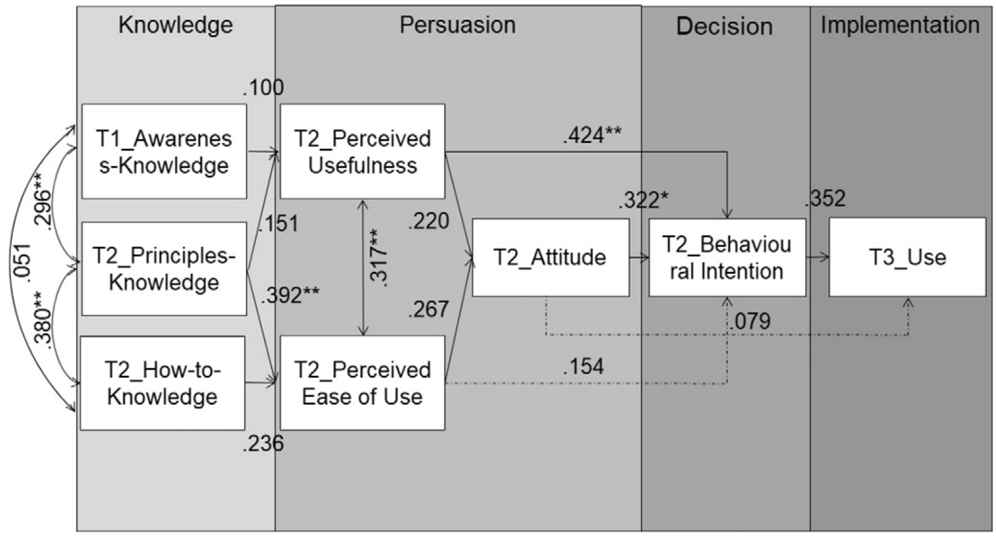

Fig. 10. Path model of the direct and indirect effect of the exogenous variables of the research model on the use behaviour in T3. Note. Awareness knowledge was measured before the intervention in T1.

were shown between T2 and T3 ($M_{T3} = 1.38$, $SD_{T3} = 0.953$, $F(1,36) = 0.063$, $p = .803$, partial $\eta^2 = 0.002$). No effect of the learning medium on the perceived likelihood of using MODS within the next four weeks was found directly after the intervention in T2 ($t(69) = -0.040$, $p = .968$), nor four weeks later ($t(35) = 1.065$, $p = .294$).

Concerning the concrete willingness to use the transport service within the next three months, no significant effect of the intervention revealed when comparing T1 and T2 ($F(1,68) = 0.330$, $p = .567$, partial $\eta^2 = 0.005$). No effect of the learning medium on the behavioural intention was found directly after the intervention in T2 ($t(69) = -0.812$, $p = .419$), nor four weeks later ($t(27) = -0.365$, $p = .718$).

3.5. Implementation stage

In T3, only one participant stated to have used the mobility on demand system in the past four weeks (1.4%). The person concerned had used the local MODS before and belonged to the experimental group. Due to the low usage number, no significant effect of the learning medium on the use behaviour was found ($t(37) = 0.876$, $p = .386$).

3.6. Path modeling

To describe the dependencies between the variables of the research model, a path analysis was conducted. Path analysis is special case of structural equation modeling based on a structural model that describes the casual influences of exogenous variables on endogenous variables (Golob, 2003). Fig. 10 presents the results of regression analysis for the experimental group and describes the relationship of the variables by the path coefficients (standardized beta coefficient). As shown here, the Percieved Usefulness after playing the game (T2) significantly predicted the Behavioural Intention to use MODS. As expected, the direct link between the *Perceived Ease of Use* and the *Behavioural Intention* was not significant. Neither was the direct releationship between *Attitude* and *Use* in T3. Yet, the effect of *Attitude* on *Behavioural Intention* was significant.

4. Discussion

4.1. Summary and interpretation of findings

The paper describes the application and empirical investigation of the serious game *B.u.S.* for introducing mobility on demand systems to prospective users. More specifically, the aim of the gamified approach was to raise awareness concerning the offered MODS and to counteract the lack of knowledge about the service concept as the main reason for not using mobility on demand service like *Kutsuplus* (Weckström et al., 2018). The game's effectiveness as a tool for addressing the challenges of conceptual comprehension, favourable appraisal and acceptance was assessed with the help of an experimental evaluation study in a high school. To conclude, the study found clear indications for beneficial effects of the gamified approach to address the challenge of sufficient conceptual comprehension and a positive appraisal but not for the acceptance challenge. In regards to the research model, the gamified approach proved conducive for supporting the first phases of the adoption process (knowledge and persuasion phase).

Both interventions, the online research as well as the serious game proved beneficial in enhancing participants' knowledge about the underlying principles of the mobility on demand service concept and to increase the participants how-to-knowledge concerning the functionality of the bus concept. Yet, the analysis of the post-hoc test four weeks after the intervention revealed that the group that had played the game retained more knowledge about the differences between the mobility on demand system and the fixed-scheduled bus, indicating higher principles knowledge. The study thus confirms the findings concerning the effectiveness of game-based learning as instructional method to support knowledge acquisition and concept understanding (Connolly et al., 2012; Randel et al., 1992; Sitzmann, 2011; Tennyson and Jorczak, 2008; Wouters et al., 2013) for the application in the transport sector. Contrary to the expectations, the online research proved more beneficial in supporting the knowledge acquisition concerning the how-to-knowledge. As shown, the pupils that searched online mentioned more details about the functionality of MODS and assessed their knowledge better than the ones that played the game. Apparently, online information-seeking was more suitable for providing detailed information. This finding should be reflected in the light of *Millennials* information acquisition habits that are mainly based on web-based platforms and services. A recent study revealed that adolescents most often use online search engines and social media for getting advice or how-to-information (Young, 2015). The common use of the internet as a source of information among adolescents might be an important explanation for the finding that the how-to-knowledge was higher among the participants that performed the online research.

The game proved also to be beneficial for addressing the second challenge of introducing new mobility systems to prospective users – the challenge of a favourable appraisal. The study revealed an increase in the participants' Perceived Usefulness of the mobility on demand system after playing the game, which proved to be an important determinant of a favourable appraisal of DRT systems (König and Grippenkoven, 2019a). As shown in the path model, the Perceived Usefulness affected the Behavioural Intention to use the local MODS. As intended in the game concept, the players assessed the usefulness for the transport agencies higher than by participants that dealt with the online research. This effect might be traced back to the learning through role play that has shown to improve player's cognitive and emotional involvement (Colucci-Gray, 2004) and might facilitate the change of players' perspective. However, the assessment of the perceived usefulness decreased in both groups after four weeks. Playing the game also was linked to a higher perceived usefulness concerning the improvement of individual mobility in the post-test four weeks after the intervention. Interestingly, the control group of pupils that researched online assessed the benefits for the environment of MODS better than the pupils that have played the game. One possible explanation might be the game mechanics that required fast players' reactions. Due to the high number of rides and number of empty runs depending on the player's strategy, the service might be perceived as inefficient or little sustainable by the players. Another explanation is the environmentally-friendly framing of MODS at websites like "Dial-a-ride services are modern, flexible, environmentally-friendly and fast transport means […]" (Deutsche Bahn, 2019, translated from German).

The analysis of participants' free associations concerning MODS showed an increase in the valence of their appraisal ratings after the intervention in both groups. Interestingly, the valence increased in both directions after the intervention – participants' appraisal became either more positive or more negative. Apparently, dealing with the mobility concept intensified their opinion with regard to MODS. No significant differences were found concerning the attitude between participants that played the game and participants that performed the online research. The findings are in line with the results of a literature review by Soekarjo and van Oostendorp (2015), who found empirical research about the effectiveness of persuasive games on change of attitude to be still sparse. Thus, it cannot be concluded that playing a game leads to a greater change in attitude than experiencing a conventional medium of information acquisition like online research.

With respect to the phase of decision, the evaluation study revealed an increase in the willingness to use MODS for both groups after the intervention. Yet, the analysis showed no differences between the two groups indicating that playing the game did not enhance usage intention more strongly than the online research as has been expected. It must be noted that after the intervention, participants of both groups assessed the probability of using the local MODS within the next four weeks as very low ($M = 1.44$, $SD = 0.92$). Hence, the missing link between playing the game and an increased willingness to use MODS might be traced back to a floor effect as all of the responses are clumped at the lower end of the scale. Another possible explanation is the intended perspective change that was facilitated by the role game. Yet, to emphasize with the character's role might have impeded the pupils' feeling of being addressed and personal consternation.

A possible floor effect might as well represent an explanation for the missing effect of the serious game on the actual use of the local mobility on demand system four weeks after the intervention. Only one participant stated to have used the MODS during the period concerned. Yet, a considerable number of further studies failed in revealing a positive effect of serious games on actual behaviour. A meta-analysis by DeSmet et al. (2014) found that the majority of the quantitative validation studies produced heterogeneous results and only few showed small overall effects of serious games on healthy lifestyle behaviour. As reasons for not having used the MODS, the respondents primary answered "no need" and more specifically "I prefer riding bike". They mentioned also "costs", "long wait times" and "environmental concerns" as reasons for not using the service. The named reasons thus underline the importance of prior conditions such as needs for behavioural changes. However parents that drive their children to hobbies represent a relevant share of the traffic volume in Germany (Nobis and Kuhnimhof, 2018). Offering an alternative for those accompanying trips could be an interesting field for the beneficial use of MODS.

4.2. Limitations and further research needs

Within the development process and the application of the serious game *B.u.S.* the researchers faced several challenges that are reported in detail in Freese et al. (2019, in preparation). In the following, challenges faced in the application of the serious game as tool for the introduction of mobility on demand services will be reflected.

First, it has to be considered that the chosen evaluation approach affects the outcomes of the evaluation studies. The selection of an appropriate task for the control group was an important prerequisite for the study design since it should be ecological valid on the one hand as well as comparable to the gaming task of the experimental group on the other hand. The online research task was chosen since the majority on teens use the internet for information-seeking (Micheli, 2015). Yet, it was hard to control for what information the pupils of the control groups searched for. Another limitation of the study design was that the game was played only once and only for 15 min as this was the average time needed to finish the sixth level. According to the procedural rhetoric framework of *B.u.S.*, 15 min were enough to provide the relevant information the game aimed to impart. Furthermore, studies suggest that pupils' attention span last about 10 to 15 min (Benjamin, 2002) even though a wide-ranging debate on the topic has opened up (Wilson and Korn, 2007). A longer game play would have not necessarily mean a better knowledge acquisition as studies found that longer play duration revealed only minor improvements or no effects on the knowledge improvement of players (Dunbar et al., 2013; Veinott et al., 2013). Yet, the study by Veinott et al. (2013) indicated that repeated game sessions facilitate good learning improvements. Thus, a starting point for further research could be an extended study design that uses repeated game sessions. Adding on this, numerous empirical studies proved that behavioural changes towards more sustainable mode choices take time as routines and habits are persistent (Chen and Chao, 2011). Thus, long term studies are necessary to evaluate actual transformation effects of gamified approaches.

Furthermore, the authors like to emphasize that the findings of the study are restricted to the specific study context. Due to the study design and the selection of the participants, the transferability to other settings is limited. It should be considered that the pupils' participation in the experiment was to some kind mandatory as the study was conducted during a regular school class. It can be assumed, that the results might differ from other groups of participants if they participate during their leisure time or are older and thus less digital-native.

For interpretation of the findings it should be considered that the data was collected with the help of questionnaires before, after and four weeks after the experiment. Since the study's aim was to assess the effect of the game on the knowledge, attitude and willingness to use mobility on demand systems, subjective data collection measures represent a valid instrument. Even though the survey-based data collection as a quantitative measure is a widespread instrument in psychological and sociological research (Rossi et al., 2013) as well as serious game research (Smith et al., 2015), using questionnaires is often accompanied by challenges concerning unintended response effects and measurement errors (Rossi et al., 2013). Thus, in planning and conducting the questionnaire study the guidelines of the American Psychological Association were regarded (Cooper et al., 2012).

A further shortcoming of the study design is the fact that no in-game metrics were collected like the achieved goals, the times spend on each level and obstacles occurred in playing the game. Yet, this data could have contributed to reflecting the findings from the survey and provide insights into individual's game performance. Accordingly, applying a mixed methods approach for data gathering in the serious game context was proposed by Mayer et al. (2014).

Furthermore, for the interpretation of the results it has to be considered that the intended learning results highly depend on the game mechanics and properties of the serious game (Ritterfeld et al., 2009). In a literature review, Connolly et al. (2012) found a sizeable proportion of papers reporting unintended outcomes of playing. As an example, the presented study found a negative effect of the serious game on the perceived environmentally friendliness of MODS compared to the control group. A recommended improvement of *B.u.S.* would therefore lie in the supplement of a private car for a comparison of the environmentally sustainability of different transport modes. That way, the environmentally benefits of MODS compared to the use of private cars could be visualized. Further studies could also address the topic of individual concerns and the feeling of affectedness by the topicto facilitate the willingness for behavioural changes. Adding further characters and roles to the game, especially a first-person character might support the feeling of being addressed and facilitates the transfer of the gained knowledge and awareness to the daily life of the players.

Based on the evaluation study several improvements for the serious game could be derived, like adding a private car as another reference besides a fixed-scheduled bus to the game. Furthermore, adding a user perspective by a first-person character to *B.u.S.* is recommended to demonstrate the beneficial effects (e.g. short waiting times) as well as the trade-offs (e.g. detours caused by fellow travelers). To conclude, the authors recommend an iterative design and development process of games for research that allows for the adaptation of game mechanics according to the findings of early evaluation studies. Furthermore, other research models could be applied to assess the user needs and factors contributing to user acceptance that go deeper into the human needs by taking further determinants of human behavior such as self-determination, fears or relatedness into account (Dreßler et al., 2019).

4.3. Recommendations for the application of serious games for facilitating knowledge acquisition and adoption

Based on the experiences made in developing and applying *B.u.S.* several recommendations can be derived that might support further research activities that aim to use gamified approaches for facilitating the adoption of new technology or services. First of all, it should be emphasized that the use of gamified approaches requires the researchers control over the mechanics and the application of the game. According to Donchin (1995): "A game is useful as a research tool if, and only if, the investigator can exercise systematic control over the game's parameters" (Donchin, 1995, p. 218). Thus, writing an own game is highly recommended to have full control over the game and its effects on players. Accordingly, as mentioned before, goals and aims of the serious game should guide the process of game design and development. Thus, game mechanics should be adapted to the objectives and purpose of the game as unintended outcomes are otherwise not uncommon (Connolly et al., 2012). Yet, it is not recommended to design a serious game that meets all objectives at once but to create different games for different purposes like to facilitate knowledge acquisition, to raise awareness or to prompt behavioural change. In line with previous research, our study suggests that serious games for persuasion and behavioural change should enable self-directed discovery (Ferrara, 2013).

Researchers should also prove whether their research objective requires a serious game or whether gamification approaches might be more appropriate to affect behaviour in incentivizing behavioural changes in routines and habits since gamification is integrated into the daily life of the person (Kazhamiakin et al., 2015; Liyanage et al., 2019; Sailer et al., 2017). Defining the core message of the research is a promising approach to decide for the appropriate tool and design it around the clear core aim (Ferrara, 2013).

When designing and applying games for learning purposes the narrow line between too few abstraction of the complex reality and too much simplification should be considered. As Michael and Chen (2006) state: "The simplification and definite rules of simulation models are one of their greatest strengths, but they are also the potential source of the greatest weaknesses" (Michael and Chen, 2006, p. 33). Ferrara (2013) state that persuasive games should be tied to the real world in order to be credible. On the one hand, an abstraction and simplification of the real world is needed for ensuring an actual game play. Thus, a comprehensive analysis of the game's objectives is needed to define where exactly a high degree of realism and complexity is needed and where a higher degree of abstraction is useful. This simplification must be met by a comprehensive debriefing and reflection phase to ensure the transfer of the learned to the real world. The use of a written debriefing or a reflection of the just experienced content is highly recommended for any application of serious games. Beyond that, the importance of fun to get players to play the game should not be forgotten. As Cooper et al. (2010) state: "We can take lessons from traditional game design to do this: rewarding players and keeping them interested are necessary for any game" (Cooper et al., 2010, p. 47).

Giving regard to the growing demands for citizens' participation and public engagement in transportation planning (Quick, 2014), serious games might be an interesting method to involve citizens in the process. By doing so, serious game might contribute to obtain public legitimacy and co-create a plan that satisfies the mobility needs of people as requested in the Sustainable Urban Mobility Plan (Langweg et al., 2014). The *City of Helsinki's Participation Game* is one recent example for the gamified involvement of citizens and co-creation with residents in the operations and services of the city (City of Helsinki, 2019). The presented game proved to be an efficient instrument for facilitating knowledge acquisition and improve players' attitude. Giving regard to the benefits of the game, the authors plan to use *B.u.S.* for participatory processes in the context of sustainable transport planning.

5. Conclusions

The paper presented a digital learning game, a so called *serious game*, to introduce mobility on demand concepts to prospective users since missing knowledge about the operation concept and lack of understanding are essential usage barriers. The ability of the serious game to enhance players' knowledge and conceptual understanding, to improve the appraisal of the mobility system and to strengthen the willingness to use was tested in an evaluation study. The comparison with a control group, performing an online research on the topic, showed that players' principles knowledge and perceived usefulness of the mobility service increased more strongly. Dealing with the topic improved participants' willingness to use the service independently of the intervention. It was shown that the Perceived Usefulness was a powerful predictor of the Behavioural Intention to use the service. To conclude, the study found strong evidence for beneficial effects of the gamified approach to address the challenge of sufficient conceptual comprehension by enhancing the awareness and principles knowledge of the players. The gamified approach of *B.u.S.* emerged as a tool that is not less effective for facilitating the adoption of MODS than a conventional online research but proved to be more beneficial than the online research in terms of knowledge long-term retention and a higher perceived usefulness concerning MODS.

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Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2019.100079.

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Attachment C - Publication 3

König, A. & Grippenkoven, J. (2020). Travelers' Willingness to Share Rides in Autonomous Mobility on Demand Systems Depending on Travel Distance and Detour Factor. *Travel Behaviour and Society, 21*, 188-202. https://doi.org/10.1016/j.tbs.2020.06.010

A.K. provided the research idea.

A.K. prepared these samples

A.K. developed the stated preference study

A.K. designed / planned / executed the study

J.G. gave research assistance.

J.G. gave methodological advice.

A.K. conducted the measurements.

A.K. took part on the data collection.

A.K. analyzed the data

J.G. supported the data analysis.

A.K. wrote the manuscript.

J.G. contributed to writing and improving of the manuscript.

J.G. contributed to revising the manuscript.

A.K. supervised the project.

J.G. gave scientific advice / constructive feedback

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Travellers' willingness to share rides in autonomous mobility on demand systems depending on travel distance and detour

Alexandra König*, Jan Grippenkoven

Institute of Transportation Systems, German Aerospace Center (DLR e.V.), Lilienthalplatz 7, 38108 Braunschweig, Germany

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ABSTRACT

Autonomous mobility on demand systems (AMODS) are predicted to face a bright future for providing convenient individual mobility. Yet, increasing the occupancy rate of AMODS by ridesharing is an essential prerequisite for sustainable future mobility. The online study (N = 150) assessed travelers' willingness to share rides with unknown fellow travelers in *shared* AMODS (SAMODS) depending on the factors *travel distance* and *detour factor* that are affected by the ridesharing scheme. The findings reveal great acceptability of SAMODS and underline the importance of the travel time and detour for respondents' willingness to share rides. The cumulative distribution function of the *Willingness to Accept (WTA)* of sharing rides provides an indication of how much discount in price of a shared ride is needed to attract a critical mass of travelers. The findings indicate that 90% of respondents would prefer to share a ride of 10 min if the discount was 50% or more compared to a private ride. A higher discount is needed to attract travelers to share rides if travel time and detour factor increase. The results highlight the importance of a price system that is adjustable to ride-specific travel time and detour factor to attract travelers to share rides in future SAMODS.

1. Introduction

1.1. The need for sharing rides in autonomous mobility on demand systems

The mid and late 2010s were characterized by a rapid change of travel patterns towards shared mobility solutions like Uber, DiDi or Lyft (Feigon and Murphy, 2018). The sharing of resources is nothing new in itself, but as the ongoing progress of digitalization supports the provision of real-time information, the sharing of resources is greatly facilitated by easing access. Thus, we are witnessing a societal change of consumer behavior towards so called *collaborative consumption* or *shared economy* in various areas of life like consumer goods (e.g. *Spinlister*), accommodation (e.g. *AirBnB*), as well as data sharing and cloud computing (e.g. *Dropbox*) (Haucap, 2015). Personal mobility is just another area of daily life that is currently undergoing changes towards *shared mobility*: "In past decades, sharing a vehicle with unknown passengers was not popular. Today, there is a significant positive psychological change toward shared mobility. This has partly been encouraged through sharing economy models in mobility, which has facilitated new transport solutions such as car sharing, ride sharing, bike sharing, and ride sourcing" (Liyanage et al., 2019, p. 7).

Adding on to the trend of sharing goods and information, the so called *on-demand economy* is currently changing individual travel patterns as well. As today's society "wants what it wants, at the exact moment it wants it" (PwC, 2015, p. 26). Personal mobility is required to meet the highly spontaneous and flexible demand of travelers. *Mobility on demand systems* (MODS) are neither based on fixed routes nor rigid timetables but operate in a demand-oriented way (Beiker, 2016; König et al., 2017). The route of these MODS is calculated and adjusted by a routing algorithm in real-time according to the ride requests of travelers booked via mobile applications. This way, MODS could be efficient to cover the *first and last mile* in the passengers' travel chain (Djavadian and Chow, 2017; Quadrifoglio and Li, 2009).

With automation, the share of today's MODS like Uber, Lyft or Via (Rayle et al., 2016) in the modal split will probably increase because automation is assumed to be the building block that promotes these systems from niche services to the mainstream market of mobility (Kickhöfer and Kröger, 2017). Driverless vehicles of SAE level 5, so called *full automation* (SAE, 2016), are predicted to have a promising future since they have the potential to contribute to a more efficient and safe transportation system (Fraedrich et al., 2015; Friedrich, 2015; Greenblatt and Shaheen, 2015) There are few pilot projects that operate driverless bus shuttles in a real-world environment (Eden et al., 2017; Madigan et al., 2017) and even fewer autonomous shuttles that operate

Abbreviations: AMODS, autonomous mobility on demand system; SAMODS, shared autonomous mobility on demand system; MODS, mobility on demand system

* Corresponding author.
E-mail addresses: alexandra.koenig@dlr.de (A. König), jan.grippenkoven@dlr.de (J. Grippenkoven).

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in a demand-driven way without serving a fixed route (Beiker, 2016). The World Economic Forum emphasizes the potential benefits of autonomous driving technologies for future mobility: "The advent of AVs will be a key driver of growth in overall mobility-on-demand" (World Economic Forum, 2018, p. 10). Yet, studies also point out threats of vehicle automation for future transport systems (i.e. COWI and PTV, 2019; Harper et al., 2016). In a recent study, the World Economic Forum states that traffic volumes in cities will likely increase due to the dissemination of autonomous vehicles (World Economic Forum, 2018). Furthermore, a study by Trommer et al. (2016) proposes that AMODS will most likely generate empty runs through the necessity of vehicle relocation. Thus, Harper et al. (2016) emphasize the inherent danger of automated vehicles to increase vehicle kilometres traveled (VKT) by increasing mobility and access of underserved persons, like the disabled. Accordingly, a recent simulation study for the City of Oslo suggests that autonomous vehicles used as private cars can worsen the traffic situation in terms of an increase in VKT if they are used in carsharing schemes instead of ridesharing (COWI and PTV, 2019). Thus, to avoid future gridlocks in inner-city traffic as a consequence of autonomous vehicles that are used as private modes of transport, approaches to incentivize ridesharing and to increase the occupation rate of public mobility services need to be closely investigated and promoted (Bösch et al., 2017; COWI and PTV, 2019; Tirachini and Gomez-Lobo, 2017). Tirachini and Gomez-Lobo (2017) state that "[…] ridesharing is a key to the impact of the new mobility technologies on VKT" (Tirachini and Gomez-Lobo, 2017, p. 25). Ridesharing refers to a mobility concept based on vehicles that are shared by different people at the same time and not successively like in ridehailing services such as *Uber* (Morency, 2007). To differentiate autonomous mobility on demand systems that are not shared (AMODS) from *shared* autonomous mobility on demand systems that are based on the concept of ridesharing, they are hereinafter referred to as *SAMODS*. In the future, SAMODS could become attractive public transport services that supplement existing mass transport (Trommer et al., 2016). Several recent simulation studies revealed that the number of vehicles in cities could be significantly decreased by the deployment of SAMODS (Alonso-Mora et al., 2017; Fagnant and Kockelman, 2014, Friedrich et al., 2018). Furthermore, the emergence of SAMODS can be a turning point for public mobility as it has great potential to make public transportation more attractive and to be more competitive compared to the use of private cars (Atasoy et al., 2015b; König and Grippenkoven, 2017; Steck et al., 2018). Thus, SAMODS may provide important alternatives to private transport "[…] and may even dramatically disrupt the status quo in a few years' time, if accepted widely" (Greenblatt and Shaheen, 2015, p. 74).

The study presented here aims to assess travelers' willingness to share rides in autonomous mobility on demand systems as the prospective dissemination of driverless mobility systems needs a broader scientific examination that goes beyond technical issues but includes an in-depth analysis of issues at an individual and societal level (Fraedrich and Lenz, 2014). The study at hand adopts an exploratory approach as empirical findings concerning travelers' perspective on shared autonomous mobility on demand systems are limited. This is because driverless vehicles have not been commercialized yet and there are only few pilot projects.

1.2. Literature review on travelers' willingness to share rides in autonomous mobility on demand systems

Besides an increasing number of scientific studies on the acceptability of individually used autonomous vehicles (i.e. Gkartzonikas and Gkritza, 2019; König and Neumayr, 2017), empirical findings concerning users' perspective on shared autonomous transport are still scarce. The service concept of shared autonomous mobility on demand systems is rarely regarded in research (e.g. Fraedrich et al., 2016; Krueger et al., 2016; Lavieri and Bhat, 2018). A study by Krueger et al. (2016) was one of the first studies to focus on the service concept of SAMODS. The study revealed that the adoption of SAVs is likely to depend on service attributes as well as individual characteristics. Lavieri and Bhat (2018) focused more on ridesharing aspect of SAMODS by studying the travelers' willingness for sharing rides with strangers. Besides the promising potentials of SAMODS for environmental sustainable, economic efficient and user friendly mobility, Fraedrich et al. (2016) observed great scepticism of respondents concerning autonomous driving when asked to imagine the service concept of so called vehicle on demand that is comparable to SAMODS. About two thirds of the respondents showed slight or strong unwillingness to use such systems (Fraedrich et al., 2016). The research at hand thus contributes to the research gap that opens up due to the limited number of empirical research in the context of SAMODS. Still, little is known about the question how people will embrace the service concept. In this context, it seems of outermost importance to study the mechanism that might encourage travelers to share the ride with strangers to facilitate the adoption of shared autonomous mobility-on-demand systems. An important research needs lies therefore in the questions, how far do service characteristics affect travelers' willingness and which incentives might encourage travelers to use SAMODS instead of traveling alone in AMODS?

The individual's acceptability of shared rides in SAMODS is expected to be based on two main factors – the service concept and the individual's characteristics (Krueger et al., 2016). The literature concerning the main factors is discussed in the following.

Regarding the service concept, research recurrently underlines the importance of *travel time* and *trip length* for travelers' appraisal of a transport system (Beirão and Cabral, 2007; De Oña et al., 2013; Jianrong et al., 2011). A recent study regarding autonomous public transport systems of the World Economic Forum revealed that the acceptability of such transport systems is linked to the trip length – the longer the trip, the lower the respondents' acceptability (World Economic Forum, 2018). Correspondingly, König and Grippenkoven (2019) showed that besides price the travel time was of highest relevance for the respondents' appraisal of ridepooling systems and travel time to be especially relevant for younger participants in the study. Thus, as a first hypothesis guiding the research, *travel time* it is expected to affect the willingness to share rides in SAMODS as shown for ridepooling systems by König and Grippenkoven (2019) and for autonomous shuttles by the World Economic Forum (2018). Since the operational concept of SAMODS implies dynamical changes of travel time caused by the pick-up and drop-off of further travelers, the resulting detour is supposed to affect the travelers' willingness to use SAMODS. Zhang et al. (2016) found travelers to be very sensitive to long detour distances and high traffic congestion rates when using a shared taxi. To conclude, it can be assumed that travel time might be an important antecedent of travelers' willingness to use SAMODS. Moreover, it seems reasonable to expect the willingness to share rides in SAMODS to decrease when a high detour results from the access and egress of other passengers due to the matching of trip chains. As a second hypothesis, the *detour* caused by the access and egress of fellow passengers is supposed to negatively correlate with the ltravelers' willingness to accept shared rides (König and Grippenkoven, 2019; Zhang et al., 2016).

Price is often considered one of the most important service characteristics for travelers' assessment of transport systems (De Oña et al., 2013; Jianrong et al., 2011; Redman et al., 2013). Price had further proved to be the most important factor of travelers' appraisal of ridepooling (König and Grippenkoven, 2019) and ridesharing services, also called carpooling (Ciasullo et al., 2018; Malodia and Singla, 2016). Thus, monetary incentives might be a powerful measure to encourage travelers to share rides in SAMODS. As outlined in the scenario *triumph of public transport* the service of autonomous vehicles might be based on a pricing system that favours the use of SAMODS over AMODS to incentivize sharing (VDV, 2015). Research assumes that the costs for trips in SAMODS will be significantly lower than today's taxi services (Bösch et al., 2017; Litman, 2018; Keeney, 2017; World Economic Forum, 2018). Based on their calculation Bösch et al. (2017) expect pooled driverless taxis that are comparable to SAMODS, to be the cheapest motorized transport mode in the future. This would leave some room for more flexible pricing schemes to favour shared rides over individual ones. The World Economic Forum (2018) suggests that policy-makers should give incentives for using shared mobility concepts by applying an occupancy-based pricing scheme that makes single-occupancy rides more expensive. Accordingly, Martinez et al. (2015) proposed a discount scheme for a new shared taxi service for the city of Lisbon that offers a 40% discount to travelers if the ride is shared with another passenger and 55% if the ride is shared with two other travelers. In Hamburg, a pricing scheme that rewards sharing rides is already in operation - *MyTaxiMatch* offers a 50% discount in taxi fare if travelers accept to share rides with fellow passengers (Betzholz, 2017). A research gap remains regarding the travelers' sensitivity for the costs of shared rides in SAMODS and the motivational effect of discount schemes. Does a 40% discount effectively encourage travelers to share their rides with strangers? Which level of discount is needed to make the shared ride more attractive than the non-shared ride? And how do service (e.g. detour factor) as well as trip characteristics (e.g. trip duration or trip purpose) and traveler's characteristics (e.g. age or gender) affect the willingness to share rides in SAMODS in terms of the discount needed? To the best of the authors' knowledge, there are no empirical results concerning the effect of the pricing scheme on the travelers' willingness to share rides in SAMODS and the moderating effect of sociodemographic characteristics, as well as trip and service characteristics of those systems. Based on the importance of the service attribute price in studies of transport mode choice (De Oña et al., 2013; Jianrong et al., 2011; Redman et al., 2013) and empirical findings showing that monetary incentives are powerful measures to encourage individuals to change their behavior (i.e. Lanzini and Thøgersen, 2014), the research gap opens up to define a discount scheme that encourages travelers to share their trips with strangers. Thus, the hypothesis can be derived that a pricing system can be effectively used as an incentive to encourage shared rides.

Besides characteristics of the operational concept, previous work suggests that individual characteristics, especially sociodemographic factors related to the passengers like gender, age, income or their place of residence might influence the willingness to share rides. Research also emphasizes the relevance of personal norms and attitudes for the acceptability of autonomous vehicles (Fraedrich et al., 2016). Yet, the examination of attitude-based differences in the travelers' willingness to share rides is not in the focus of this study.

Since women are supposed to assess their experience of safety in a driverless bus shuttle worse than men (Shalonen, 2018) and have security concerns when using shared ridehailing services (Sarriera et al., 2017), the negative effect of travel time and detour on the willingness to share rides in SAMODS is expected to be stronger for female travelers. A study by Lavieri and Bhat (2018) revealed that women are less likely to choose the shared option in a stated choice experiment concerning autonomous shuttles. Besides gender, research suggests that age might have an influence on the willingness to share rides. So called *early adopters*, mostly young, well-educated men tend to be more open to use mobility on demand services like *uber* (Alemi et al., 2018) and *Vehicle on Demand* services that are comparable to SAMODS (Fraedrich et al., 2016). It is sensible to assume that this effect might also be found regarding SAMODS. Accordingly, Gilibert et al. (2017) found that the youngest group of survey respondents (aged 18–29 years) showed the highest intention to use shared ridehailing services that are comparable to MODS. Accordingly, Krueger et al. (2016) showed that young individuals may be more likely to adopt autonomous vehicles. Lavieri and Bhat (2018) revealed that a higher income increased the likelihood to share the ride in autonomous shuttles. Thus, it can be assumed that young age and high income are positive predictors of a higher willingness to share rides in SAMODS. Besides age, gender and income, the place of residence is expected to have an impact on the travelers' willingness to use SAMODS. Anspacher et al. (2005) calculated the Willingness to Pay (WTP) for a demand-responsive rail feeder service and found residents of urban areas less willing to pay for the shuttle than suburbanites. The authors argue that it might be possible that urban residents are more price-sensitive since they have a wider range of transportation options available to them (Anspacher et al., 2005).

Based on the literature review a forth hypothesis can be derived that states that the sociodemographic variables age, gender, income and place of residence are expected to affect the willingness to share rides in SAMODS. It is assumed that an older age (Fraedrich et al., 2016; Gilibert et al., 2017), female gender (Lavieri and Bhat, 2018; Shalonen, 2018) a lower income (World Economic Forum, 2018) as well as non-urban place of residence (Anspacher et al., 2005) are related to a decreased willingness to use SAMODS.

To conclude, the study aims to answer to the following questions: How do travel time and detour factor influence travelers' willingness to share rides in SAMODS and in which way do sociodemographic characteristics affect this relationship? By answering those questions the study aims to support policy makers and transport planners to identify measures and incentives to attract travelers to share rides in future autonomous mobility on demand systems.

2. Material and methods

2.1. Measures

An online survey based on the software *SosciSurvey* was used to answer the research questions (Leiner, 2014). Although online surveys face some important challenges in external validity when applied for studying future systems and services, they are frequently used for an explorative assessment of prospective users' appraisal of innovative systems like self-driving cars (Alessandrini et al., 2014; Bansal et al., 2016; Fraedrich et al., 2016; Tussyadiah et al., 2017).

A Stated Preference (SP) experiment was chosen as a technique to examine user preferences for services that are not yet available in the market (Dell'Olio et al., 2011; Matyas and Kamargianni, 2017). In the field of transportation research, SP techniques are frequently used to analyze influential factors for choice behavior and the willingness to use (e.g. Chang et al., 2013; Krueger et al., 2016). The SP technique has also been applied to the field of autonomous vehicles (Gkartzonikas and Gkritza, 2019; Kyriakidis et al., 2015). The study used the method of open-ended contingent valuation method (CV) as a form of SP experiments to elicit the respondents' willingness to share rides in autonomous mobility on demand systems (Boyle, 2017). CVs aim to assess whether an individual would choose a proposed change at a specific cost, i.e. accept a longer travel time due to the access of fellow travelers (Johnston et al., 2017).

The first dependent variable was the amount of money the respondents of the survey would be willing to spend for a shared ride in an autonomous mobility on demand system compared to a non-shared ride. The dependent variable willingness to share rides was realized through the construct *Willingness to Accept* (WTA). The WTA is defined as the size of the financial discount that is needed as a compensation for accepting to abandon a good or to put up with something negative (O'Sullivan and Sheffrin, 2008). The WTA stands in contrast to the construct of Willingness to Pay (WTP). The WTP refers to the maximum amount an individual is willing to pay for a good or a service whereas the WTA is the minimum amount an individual need to receive to accept something undesirable (Grutters et al., 2008). Thus, the WTA describes a form of compensation for being adversely affected by a change to the status quo (Whittington et al., 2017). It is a suitable dependent variable since it is assumed that most persons prefer individual rides over shared rides. The WTA was assessed by the share of the money respondents are willing to pay for a shared ride in an AMODS based on the reference value for of a non-shared ride of the route. Instead of using cost estimations in an existing currency, the fictional currency ð

Table 1
Measures of the study.

Measure	Definition	Characteristics (Range)	Unit
WTA	Compensation demand in terms of minimum amount of price reduction to accept shared ride depending on price for non-shared ride	0–100	Fictional currency ð
Refusal rate	the percentage of shared rides that were rejected by the respondents	0–100	percentage
Travel time	Original travel time for direct route	10 min, 15 min, 20 min	minutes
Detour factor	Factor of deviation from the original travel time	1.1., 1.2, 1.3, 1.4, 1.5	factor

was used to avoid a bias with regard to experiences with today's mobility costs. The default costs were set to 100 ð per 10 min ride, thus the costs for the travel time of 15 and 20 min were 150 ð and 200 ð respectively.

As another dependent measure, the *refusal rate* was defined as the percentage of shared rides that were rejected by the respondents. The refusal rate thus was used as an indicator for the willingness to choose the shared ride in autonomous mobility on demand systems.

Two independent variables were of interest for this study to predict the dependent variable WTA (Table 1). First, *travel time* of the rides with three levels: 10 min, 15 min and 20 min. The second independent variable was the *detour factor* caused by the access and egress of fellow travelers to the same vehicle. This variable consisted of five levels ranging from a detour factor of 1.1 to 1.5. Table 2 shows the 15 scenarios resulting from the combination of travel time and detour factor. The design of the SP experiment captured all options of the combination of the variables travel time and detour factor (full factorial design).

2.2. Scenarios

A fictitious booking app for SAMODS shown in Fig. 1 was used to introduce the study participants to the objective of their task. The study design (Table 1) was implemented with the help of different scenarios. Each scenario was framed as a ride in an urban setting with the objective to meet a friend since research has shown that mode shift behavior is more likely for leisure trips than for work related trips and shopping as well as social trips revealed as the most recurring purposes for trips with DRT systems (Jain et al., 2017; Vedagiri and Arasan, 2009). Two alternative routes were presented as choice options to the study participants as shown in Fig. 1: option 1) a direct, non-shared ride referred to as *reference choice* and option 2) a shared ride implying a detour caused by the access of a fellow traveler (*shared ride*). The shared scenarios were created based on the assumption that the respondents share about 50% of travel distance together in the shared autonomous vehicle. The starting and end point of a trip was the same for the two presented options. However the route changed according to the detour factor as shown in Fig. 4. In order to assess the WTA for shared rides, the participants were asked to specify the maximum value of the fictional currency ð they would pay for the shared ride (option 2). They were further given the chance to choose the alternative *I would rather not choose option 2*.

2.3. Instruments and procedure

Participants were recruited via social media platforms (i.e. *Facebook*, *Twitter* and mailing lists of universities). They were introduced to the study subject by a textual and graphical explanation regarding the vehicle concept and the operational concept of AMODS as well as the concept of sharing rides as visualized in Fig. 2 and the textbox of Fig. 3. Subsequently, they were introduced to the task of determining the maximum price they are willing to pay to accept sharing rides with strangers (see textbox of Fig. 3). For this purpose, three examples of choices were presented to the participants. Right before the start of the choice tasks, the underlying scenario was presented to the participants: they were asked to imagine a ride to the city centre to meet a friend. A trip with a leisure time activity as a purpose was chosen since it is assumed that requirements with regard to time are less rigid in this context compared to commuting trips with a business purpose (Litman, 2017).

Table 2
Study design based on travel time and detour factor.

		Detour factor				
		1.1	1.2	1.3	1.4	1.5
Travel time in min	10:00	11:00	12:00	13:00	14:00	15:00
	15:00	16:30	18:00	19:30	21:00	22:30
	20:00	22:00	24:00	26:00	28:00	30:00

Fig. 1. Example of a choice task (*10min_1.2detour*) translated from German, left: reference choice: non-shared ride and right: shared ride with detour factor of 1.2 (© OpenStreetMap, CC-BY-SA).

The participants were asked to respond to 15 choice tasks as presented in Fig. 2. The order of the choice tasks was randomized between the participants. At the end of the questionnaire, the respondents were instructed to answer several sociodemographic questions and questions regarding their regular mobility behavior. Furthermore respondents were asked to reproduce the scenario that had been introduced. The reproduction of the scenario served as a control for the thoroughness with which the participants had read the introduction. Participants that were not able to reproduce the scenario were excluded from further analysis.

2.4. Data processing and analysis

The survey was completed by 186 participants. A total number of 35

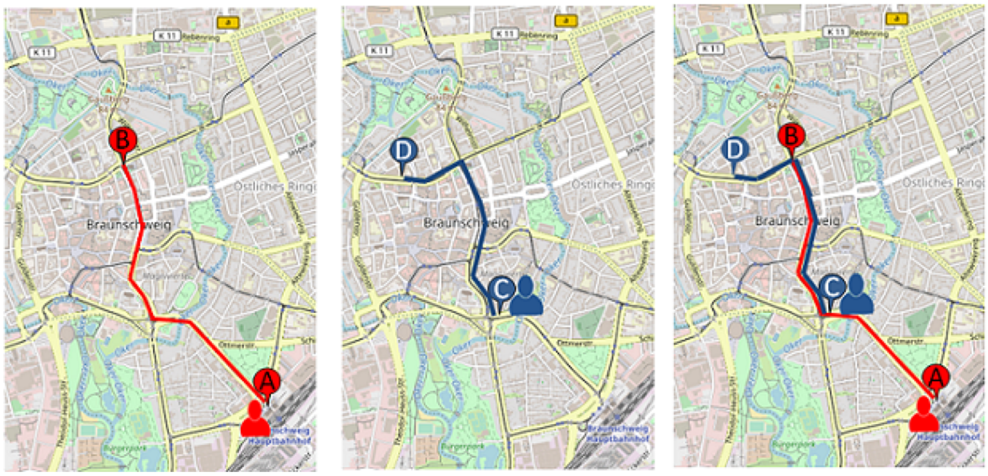

Fig. 2. Graphical explanation of the sharing concept (© OpenStreetMap, CC-BY-SA).

You may have heard of autonomous shuttles, also known as driverless taxis or robotaxis. Such driverless systems are currently being tested. In a few years it may be possible to order such autonomous shuttle via app. The autonomous shuttle will then pick you up autonomously, that is, without a driver, at the location and time you have suggested. With such autonomous shuttles, there will no longer be a fixed timetable and no fixed stops - stops and routes will be calculated when passengers have specified a desired journey. The vehicle has 8 seats and could look something like this [picture of vehicle].

The aim of autonomous shuttles is to bundle the travel requests of passengers as far as possible so that not just one person is transported per vehicle, as is the case for taxis. By pooling ride request traffic load should be reduced. An intelligent algorithm matches the routes of different travelers as presented in the picture below. Imagine the red passenger is traveling from A to B (picture 1) and the blue passenger from C to D (picture 2). In picture 3 you can see the combination of the 2 routes. In this example, no detour results for the two travelers. It is also possible that the direct route cannot be driven because another passenger is picked up off the route, resulting in a detour.

This study's aim is to examine the requirements that passengers place on such an autonomous shuttles. In particular, we would like to know what discount passengers demand for sharing the ride with fellow passengers and to accept a longer travel time. Please imagine booking an autonomous shuttle with an app that could look like the one shown below. You want to drive from A to B. The route is shown in red. In the following, two alternatives are always presented to you: Option 1: an autonomous shuttle that you use alone. Option 2: a shared, autonomous shuttle that picks up another passenger. For each option, you can see below the map view how long the journey will take (in option 1: 5 minutes from A to B, in option 2: 9 minutes from A to B). Since we cannot yet estimate how much the trip with such an autonomous shuttle will cost, we use the fictitious currency ð here. Option 1 costs 100 ð. With option 2, the amount is open because we want to know about it from you. We ask you first to indicate whether you could imagine choosing option 2 in general. If you could not imagine using option 2, please select "I would definitely not choose option 2". If you could imagine choosing option 2 for a discount on the price, please indicate the maximum that option 2 would cost so that you would prefer it to option 1 (travel alone). Important: Please always indicate the maximum amount you would still pay. Please indicate how high the price should be, which is marked as X, XX ð, so that you would rather choose option 2 (shared trip). Please enter the amount in the field below the picture.

Please imagine the following scenario to answer the question: You would like to visit a friend, but have not arranged a fixed date. So you are not under time pressure. Please think yourself into this scenario when you make the following decisions!

Fig. 3. Textual introduction of the study context used in the SP experiment (translated from German).

individuals (18.8%) were excluded from data analysis because the control variable (*Do you remember which of the following scenarios was introduced to you?*) revealed that they did not correctly remember the introduced scenario. It was therefore derived that they had not read the introduction with enough care. Another participant was excluded since the willingness to pay for a shared ride was higher than for a non-

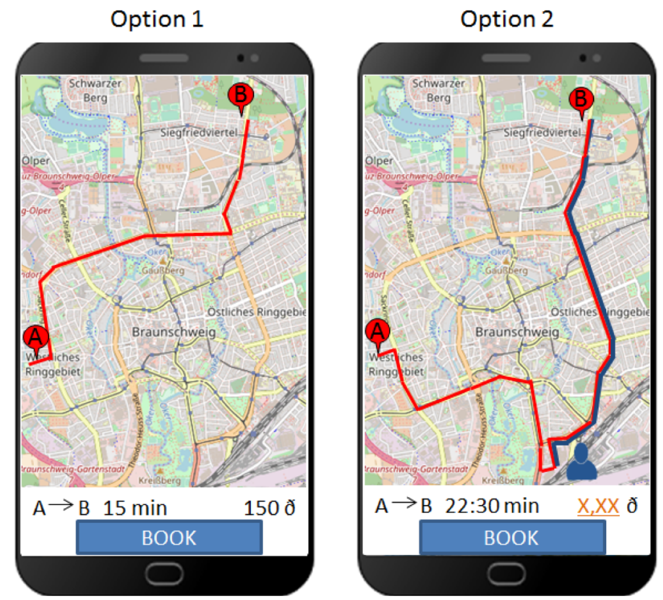

Fig. 4. Least accepted scenario *15min_1.5detour* in terms of highest refusal rate (© OpenStreetMap, CC-BY-SA).

Table 3
Sociodemographic characteristics of study participants.

Sociodemographic variable	Characteristics	n	%
Size of residence (number of inhabitants)	< 5.000	17	11.2
	5.000–50.000	33	21.8
	50.000–500.000	90	40.4
	> 500.000	35	23.2
	Missing	5	3.3
Highest educational level	No educational qualification/still in education	5	3.5
	Secondary school certificate	7	4.6
	High school graduation	31	20.5
	Vocational training	20	13.2
	University degree	84	55.6
	Missing	4	2.6
Employment status	Full-time	66	44.0
	Part-time	18	12.0
	Unemployed	5	3.3
	Retired	2	1.3
	In education	52	34.7
	Temporary out of work	1	0.7
	Missing	4	2.7
Net household income	< 1.000€	38	25.3
	1.000–2.000€	31	20.6
	2.000–3.000€	28	18.7
	> 3.000€	27	18.0
	Missing	26	17.4

shared which indicates that the individual struggled in understanding the task. For computing the WTA, the amount that participants were willing to pay for a shared ride ($ð_{shared}$) was related to the default price of the non-shared ride ($ð_{non\text{-}shared}$). The resulting percentage ($WTA_{shared} = ð_{shared} / ð_{non\text{-}shared}$) was used for further analysis of the WTA.

Data were analysed with the help of the statistical software SPSS (IBM Analytics, 2018) and R (R Development Core Team, 2007). The data analysis followed a stepwise approach. The effects of the two independent variables *travel time* and *detour factor* on the two dependent variables *refusal rate* and *willingness to accept* were modelled in distinct regression analyses. The effects of sociodemographic characteristics were included in a moderation analysis.

2.5. Participants

Participants were recruited online throughout Germany with the help of social media platforms like Facebook. The final sample ($N = 150$) was characterized by a mean age of 33.3 years ($SD = 11.8$ years). The sample consisted of slightly more men (n = 84, 56.0%) than women (n = 60, 40.0%, rest not specified). As shown in Table 3, more than half of respondents lived in cities with more than 100.000 inhabitants (62.4%). Out of the total sample, three individuals stated to be mobility impaired (2.0%). The majority of respondents declared to possess a driver's license (82.0%). However, 31.3% of participants (n = 47) stated that they do not own a car. A considerable proportion of respondents neither had previous experiences with ridesharing schemes (n = 100, 66.7%), nor carsharing (n = 105, 70.0%), bikesharing (n = 119, 79.3%) or ridepooling/DRT (n = 122, 81.3%). Only a small share of respondents had used ridesharing (n = 4, 2.6%), carsharing (n = 6, 4.0%) or bikesharing (n = 5, 3.3%) on a regular basis of more than once a month.

3. Results

3.1. Refusal of sharing rides in SAMODS

First, data was analysed concerning the rate of respondents that rejected shared rides depending on travel time and detour factor. The overall refusal rate across all levels of travel time and detour was 7.2% ($SD = 0.258$). As shown in Table 4, the mean refusal rate differed depending on the detour factor and the travel time. The mean refusal rate was higher for greater detours than for smaller detour factors. The shortest travel time (10 min) resulted in lower refusal rates than the scenarios with longer travel time. As shown here, the longest travel time (20 min) revealed a lower mean refusal rate than the 15 min trips. The least accepted scenario in terms of the highest refusal rate was *15min_1.5detour*. It was rejected in 29.3% ($SD = 0.457$) of the choice situations. As shown in Fig. 4, this scenario was characterized by a route to the opposite direction of the traveler's destination, indicating that respondents might strongly disliked detours heading the opposed direction. The comparison of the mean refusal rate revealed significant differences depending on gender of the respondents ($F(1, 2158) = 9.628$, $p = .002$, *partial* $\eta^2 = 0.004$). The mean refusal rate of women across all scenarios was lower (4.2%) than men's refusal rate (7.5%). Another finding refers to the effect of age on the mean refusal rate. Respondents aged < 33, the mean age in the sample, revealed a significant lower mean refusal rate (5.3%) than respondents aged more than 34 years (9.0%, $F(1, 2173) = 10.857$, $p = .001$, *partial* $\eta^2 = 0.005$).

First, the Heckman correction technique (Heckman, 1979) was used to test for a possible selection effect since individuals were not randomly selected. The method is suitable to produce unbiased estimates in the presence of selectivity. The two-step Heckman correction method was applied to the model using the function *Heckit* of the R package *sampleSelection*. The Inverse Mill's Ratios was −5.858e-16 and not significant ($p = .92$). Thus there is no indication for a selection problem in the model (Greene, 2003). A binary logistic regression was used to model the effect of detour and travel time on the rejection rate of the shared ride scenarios (Table 4). Results are presented in Table 5. A chi square test based on the log likelihood estimation verified the regression model ($X^2(2) = 97.930$, $p < .001$). A total share of 92.8% cases was classified correctly. *Nagelkerkes* R^2 was 0.106, indicating a medium effect size according to Cohen (Field, 2009). The regression coefficients *detour* ($\beta = 6.158$, $p < .001$) and *travel time* ($\beta = 0.049$, $p = .019$) had a significant effect on the rejection rate showing that the rejection rate increases if detour and respectively travel time are increasing. More specifically, *Exp(b)* as an indicator of the change in odds resulting from a unit change in the predictor (Field, 2009) shows that the odds of refusing a ride is 472.65 times higher when the detour increases by one unit and increases by 5% when travel time increases by one unit. It should be noted that the impact of travel time increase on rejection rate

Table 4
Mean refusal rate in percent and standard deviation in parentheses according detour and travel time.

		Detour				
		1.1	1.2	1.3	1.4	1.5
Travel time	10 min	2.0 (0.140)	2.0 (0.140)	2.0 (0.140)	5.3 (0.225)	6.7 (0.250)
	15 min	2.0 (0.140)	3.3 (0.180)	6.7 (0.250)	14.7 (0.355)	29.3 (0.457)
	20 min	2.7 (0.162)	4.0 (0.197)	4.0 (0.197)	7.3 (0.262)	15.3 (0.362)

would be more evident if the metric would be a factorial increase like for the detour factor. The regression coefficient would be 7.35 for a 1.5 time increase.

Log-Likelihood = 1061.47, *Cox & Shell* R^2 = 0.043, *Nagelkerkes* R^2 = 0.106

It should be noted that the zooming factors, that varied between the scenarios could have an impact on the respondents' assessment of the factor travel time. As shown in Fig. 5, the map was shown with a higher zooming factor, when the travel time was 10 min than 15 min or 20 min respectively. This finding is discussed in detail in the discussion section.

3.2. Willingness to accept estimation

First, the model fit was checked. The errors were independent as shown by a value of 1.305 of the Durbin-Watson test (Field, 2009). Collinearity was checked based on the variance inflation factor (VIF; Field, 2009). The VIF was 1.0, thus not pointing towards a concern for biases (Bowerman and O'Connell, 1990). Yet, Kolmogorov-Smirnov test ($D(2088) = 0.122$, $p < .001$) and Shapiro-Wilk test ($D(2088) = 0.961$, $p < .001$) were both significant, indicating a deviation from normality. Furthermore, data was left-skewed (−0.482) and kurtosis was high (−0.506). Since several of the most common statistical procedures, especially those requiring normal distribution, are sensitive to minor deviations from the assumptions (Huber and Ronchetti, 2009), robust procedures that are insensitive to small violations of the underlying assumptions should be preferred to assess the proposed model (Field, 2009). Thus, linear regression was computed using the Huber function (Fox and Weisberg, 2013). The *robustregH* function of the R package *robustreg* (Johnson, 2017) was used. RobustRegH uses iteratively reweighted least squares (IRLS) and *M*-estimation that gives less weight to or eliminates unusually large or small residuals (Wang et al., 2007; Wilcox and Keselman, 2012).

Table 6 shows the results of robust regression with Huber function. The interaction term of detour and travel time was excluded from the model due to non-significance ($t(2087) = -1.12$, $p = .264$). The regression's F-test was highly significant ($F(2,2085) = 325.05$, $p < .001$), thus it can be assumed that the model explains a significant amount of the variance in WTA. R^2 was used as a measure how much of the variability in the outcome is accounted for by the predictors (Field, 2009). R^2 was 0.306, which means that 30.6% of the variance in the WTA was predicted by the two variables detour and travel time.

As shown in Table 7, the regressors *detour* ($t(2085) = -22.14$, $p < .001$) and *travel time* ($t(2085) = -12.80$, $p < .001$) make significant contributions to predicting the WTA.

The regression function to predict the WTA is described by (1). The formula indicates that as the detour increases by one unit, the WTA decreases by 66.22 units. In contrast, the WTA decreases only by 1.29 units when travel time increases by one unit.

$$WTA_i = 174.65 - 66.22 * Detour - 1.29 * Traveltime + e_i \quad (1)$$

Fig. 6 presents the WTA of shared rides in relation to the non-shared ride depending on travel time and detour factor. As shown by the range of the whiskers that represent the 95% confidence interval, the variance of WTA is very high.

The cumulative distribution of the WTA was assessed to describe the cost sensitivity of the respondents. As shown in Fig. 7, the distribution of the WTA varied depending on travel time (left) and detour factor (right). As presented here, the share of respondents that would choose a shared system for only small discounts in price is higher when the travel time is 10 min compared to 15 min or 20 min respectively. A reference line was set at 10% of respondents. As shown at the left Fig. 7, 90% of respondents introduced to the scenario of a 10 min ride would favour a shared ride instead of a non-shared ride if the price for the shared ride is 50% of the non-shared ride's price. In comparison, the price for a 15 min ride should be 37.5% of the non-shared ride's price if a critical mass of 90% of travelers should be attracted and 32.5% for the 20 min ride respectively. As shown on the right side, a critical mass of 90% of respondents is attained if a discount of 50% is offered for a shared ride with a detour factor of 1.1. The WTA of 90% of the respondent decreases to 46.7% of the non-shared ride's price if the detour factor is 1.2 and to 37.5%, 32.5% and to 26.7% for detour factors of 1.3, 1.4 and 1.5 respectively.

3.3. Moderation analysis

For moderation analysis four sociodemographic variables were included in the model. The sample was divided according to the mean age of respondents (M = 33.3 years) with *Age* = 1 for respondents that were aged equal or more than 34 years (n = 55) and *Age* = 0 for respondents ages 33 years or younger (n = 90). The variable *Gender* was set to 1 if respondents stated to be female (n = 60), and 0 if male (n = 84). The new variable *Income* was set to 1, if respondents' net household income per month was equal or higher than 2.000€ (n = 55) and 0 if lower (n = 69). A new variable was computed with *Residence* = 1 if respondents lived in a city with more than 100,000 inhabitants (n = 90) and *Residence* = 0 if respondents lived in suburban or rural areas with < 100,000 inhabitants (n = 60).

The model presented in section 4.2 (model 1) was expanded by the interaction terms of the two independent variables *travel time* and *detour* with the sociodemographic variables *gender*, *age*, *income* and *residence*. Table 7 presents the results of the regression analysis for the interaction model (model 2). Successively, the variables that had no significant impact on the model were removed. The model was checked for multicollinearity. It was shown that the variable *income* significantly correlated with *age* ($r = 0.399$, $p < .001$) and *gender* ($r = -.049$, $p = .038$) and was thus excluded. The final model (model 3) only included variables that make a significant contribution to the model in

Table 5
Results of binary logistic regression.

	Regression coefficient	Standard error	Wald	*p*-value	Exp (B)	95% confidence interval for Exp (B)	
Detour	6.158	0.707	75.950	0.000	472.649	118.315	1888.149
Travel time	0.049	0.021	5.497	0.019	1.050	1.008	1.093
Constant	−11.618	1.046	123.405	0.000	0.000		

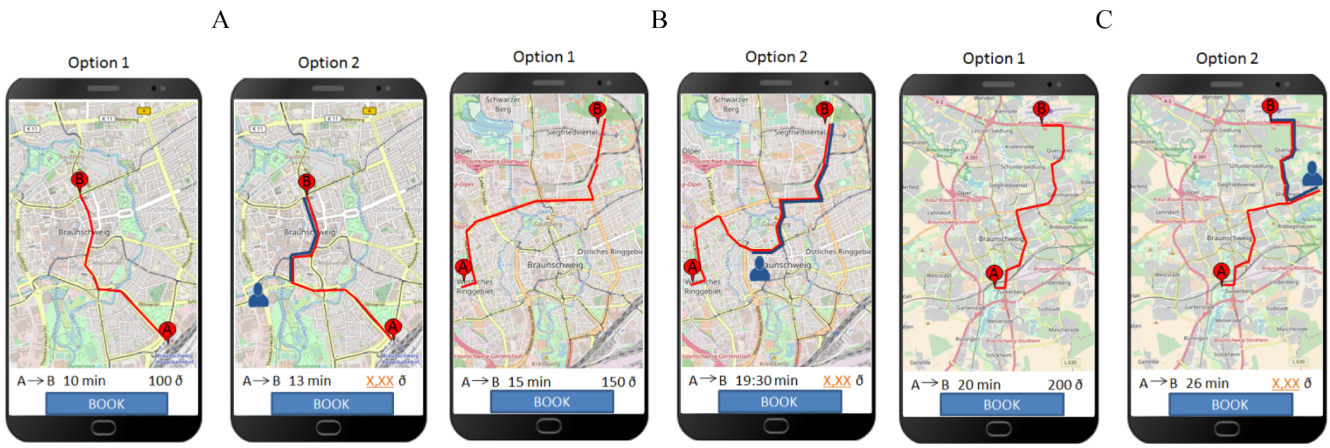

Fig. 5. Exemplary comparison of the three scenarios with a detour factor of 1.3 regarding the zoom factor A: 10 min, B: 15 min, C: 20 min (© OpenStreetMap, CC-BY-SA).

Table 6
Results of robust regression with Huber function.

	Sum of squares	*df*	R^2	*MSE*	*F*	*Sig.*
Regression	22523.9	2	0.306	245.09	325.05	0.000
Residual	511004.4	2085				
Total	736258.3	2087				

MSE = mean square error

Table 7
Results of robust regression with Huber function.

	Estimate	*Standard error*	*t-value*	*p-value*
Intercept	174.65	4.17	41.83	0.000
Detour	−66.22	2.99	–22.14	0.000
Travel time	−1.29	0.10	−12.80	0.000

terms of a significant *p*-value (Table 8). F-test was highly significant (F (5,1707) = 146.21, $p < .001$). As indicated by $R^2 = 0.319$, the model's variables explained 31.9% of the variance in the WTA. The R^2 results in a *cohens'd* = 0.67, indicating a medium sized effect according to Cohen (Cohen, 1992). Within the final model, two moderator variables and an interaction term had an influence on the dependent variable WTA besides the independent variables travel time (t (1707) = −1.23, $p < .001$) and detour ($t(1707) = -71.23$, $p < .001$). It is shown that gender had a significant effect on the WTA in a way that female gender is linked to a lower WTA (t (1707) = −14.83, $p < .001$). Age revealed a significant effect on the WTA ($t(1707) = -5.23, p < .001$). Younger respondents (< 33 years) revealed a higher WTA ($M = 103.38$, $SD = 38.94$) than the group of respondents aged more than 34 years ($M = 97.60$, $SD = 36.99$). One interaction effect gained significance within the model. Gender moderated the effect of detour factor on the WTA ($t(1707) = 12.17$, $p < .001$). As shown in Fig. 8, men were more attentive to higher detours in a way that men's' WTA for trips with a high detour factor was lower than women's WTA.

Based on the results of regression analysis, the final model is described by the formula 2.

$$WTA_i = 181.99 - 71.23 * Detour - 1.23 * Traveltime - 14.83 * Gender - 5 - 23 * Age + 12.17 * Detour{:}\ Gender + e_i \qquad (2)$$

4. Discussion

4.1. Summary and interpretation of findings

New shared mobility forms that are enabled by recent technological developments are emerging all over the world and change travel patterns, especially in urban areas. The rapid development of concepts like Uber, Lyft or Via requires a comprehensive analysis of how to design and operate these innovative shared transportation systems. Furthermore, the foresight of the anticipated dissemination of driverless vehicles necessitates research on future driverless shared mobility concepts. The aim of the study at hand was to assess the travelers' willingness to share rides in autonomous mobility on demand systems.

To summarize the findings in short, the study revealed great acceptability of shared autonomous mobility on demand concepts (SAMODS). In total, the study's participants refused to share the ride only in 7.2% of the introduced scenarios. In all other scenarios the respondents preferred sharing the ride in a SAMODS over riding alone if offered an appropriate discount. Thus, the findings are somehow contradictory to the findings of Fraedrich et al. (2016) who observed great skepticism of study participants concerning the concept of SAMODS. A part of the explanation might be found in the fact that Fraedrich et al. (2016) introduced the shared vehicle concept in the context of vehicle automation and compared it to other concepts, for example a parking pilot, that rather assisted drivers than replaced them and were appraised more positively by the study participants.

The study revealed gender and age effects on the rejection rate of shared rides in SAMODS. Men and older respondents tend to refuse the shared rise more often than did women and younger study participants. On the first sight, this result contradicts the findings, that women are more cautious when using autonomous public transport systems (Shalonen, 2018) and thus their rejection rate of shared rides should be higher for safety reasons. Yet, for the other dependent variable – the WTA, the results point to the expected direction. Female gender was linked to a lower WTA indicating that higher discount are needed to attract women to share rides. The findings thus imply that women tend to accept a shared ride more often than men but require a higher compensation for their willingness to share. There are other studies in the context of ridesharing systems that found women to be more likely to use ridesharing (Abraham et al., 2017; Brownstone and Golob, 1992). A possible explanation for the lower refusal rate of women concerning shared rides might be based on the literature, which suggests women take stronger standpoints on environmental and prosocial

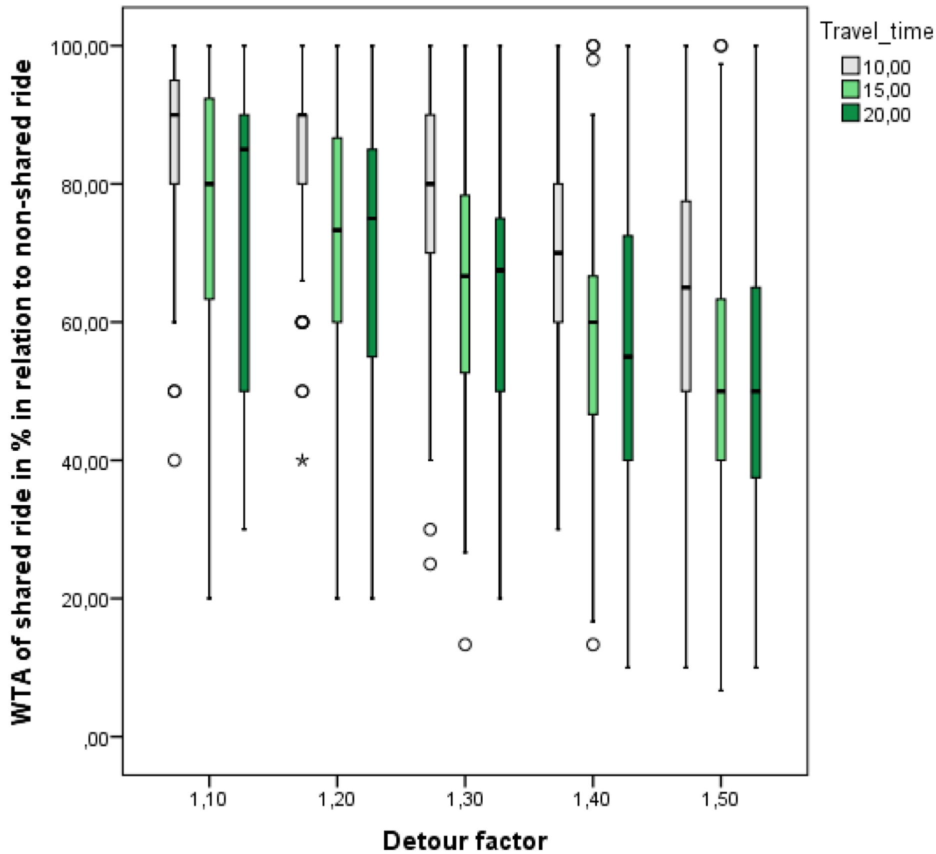

Fig. 6. Boxplot diagram representing median and 95% confidence interval for Willingness to Accept (WTA) of shared ride in % in relation to non-shared ride depending on detour factor and travel time.

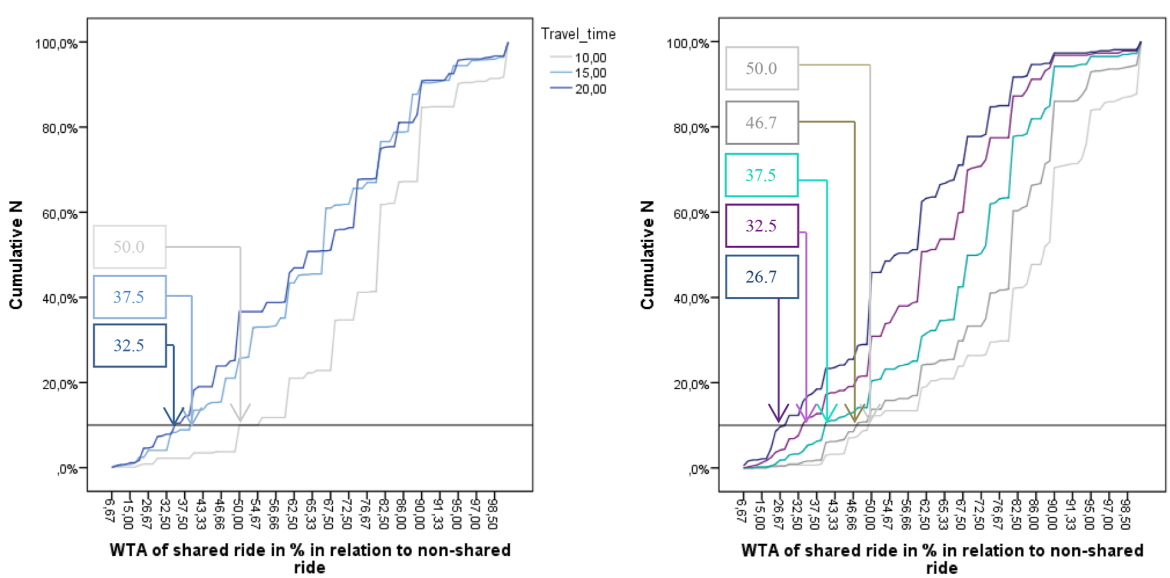

Fig 7. Cumulative distribution function of the Willingness to Accept (WTA) regarding travel time (left) and detour factor (right). A reference line was set to 10% of cumulated respondents' number and the corresponding value on the x-axis was marked to display 90% of respondents.

behavior as compared to men (O'Fallon and Butterfield, 2005). Linking this evidence with the willingness to accept shared rides and detours would require further research.

The age effect on the acceptability of SAMODS confirms findings of Madigan et al. (2017) and the World Economic Forum (2018) for autonomous public transport systems. The results further support the findings of Alemi et al. (2018) concerning the use of on-demand ride services as well as Gilibert et al. (2017) who found young age to be positively correlated with the expressed willingness to use shared ridehailing. The willingness of sharing rides in SAMODS was affected by the travel time and the detour factor in a way that higher travel times and higher detours lead to a higher refusal rate of the shared ride. The results concerning the effect of travel time on the rejection rate of shared rides thus confirm the findings of König and Grippenkoven (2019) for ridepooling systems. Accordingly, a long travel time can be perceived as an important usage barrier for sharing rides in mobility on

Table 8
Results of robust regression moderation analysis with Huber function.

	Model 1 (No moderation model)	*Model 2 (Full moderation model)*	*Model 3 (Final moderation model)*
$SS_{Regression}$	22523.9	197,830	224847.7
$SS_{Residual}$	511004.4	382407.3	480,286
SS_{Total}	736258.3	580237.2	705133.7
Intercept (*t-value*)	174.65 (*41.83*)**	180.88 (*19.26*)**	181.99 (*35.45*)**
Detour (*t-value*)	−66.22 (*–22.14*)**	−73.17 (−*10.92*)**	−71.23 (−*18.85*)**
Travel time (*t-value*)	−1.29 (−*12.80*)**	−0.94 (−*4.18*)**	−1.23 (−*12.74*)**
Gender (*t-value*)		−16.65 (−*1.89*)	−14.83 (−*1.97*)*
Age (*t-value*)		−6.27 (−*0.60*)	−5.23 (−*6.32*)**
Residence (*t-value*)		3.46 (*0.37*)	–
Income (*t-value*)		7.83 (*0.80*)	
Travel time:Gender (*t-value*)		−0.27 (−*1.25*)	–
Detour:Gender (*t-value*)		16.75 (*2.65*)**	12.17 (*2.10*)*
Travel time:Age (*t-value*)		−0.27 (−*1.06*)	–
Detour:Age (*t-value*)		5.71 (*0.77*)	–
Travel time:Residence (*t-value*)		0.05 (*0.22*)	–
Detour:Residence (*t-value*)		−3.01 (−*0.45*)	–
Travel time:Income (*t-value*)		−0.07 (−*0.28*)	–
Detour:Income (*t-value*)		−7.87 (−*1.12*)	–
df_{model}	2	14	5
F	325.05	46.46	146.21
MSE	245.086	225.078	239.305
R^2	0.306	0.341	0.319

SS = Sum of Squares, *df* = degrees of freedom, *MSE* = mean square error, ** $p < .01$, * $p < .05$.

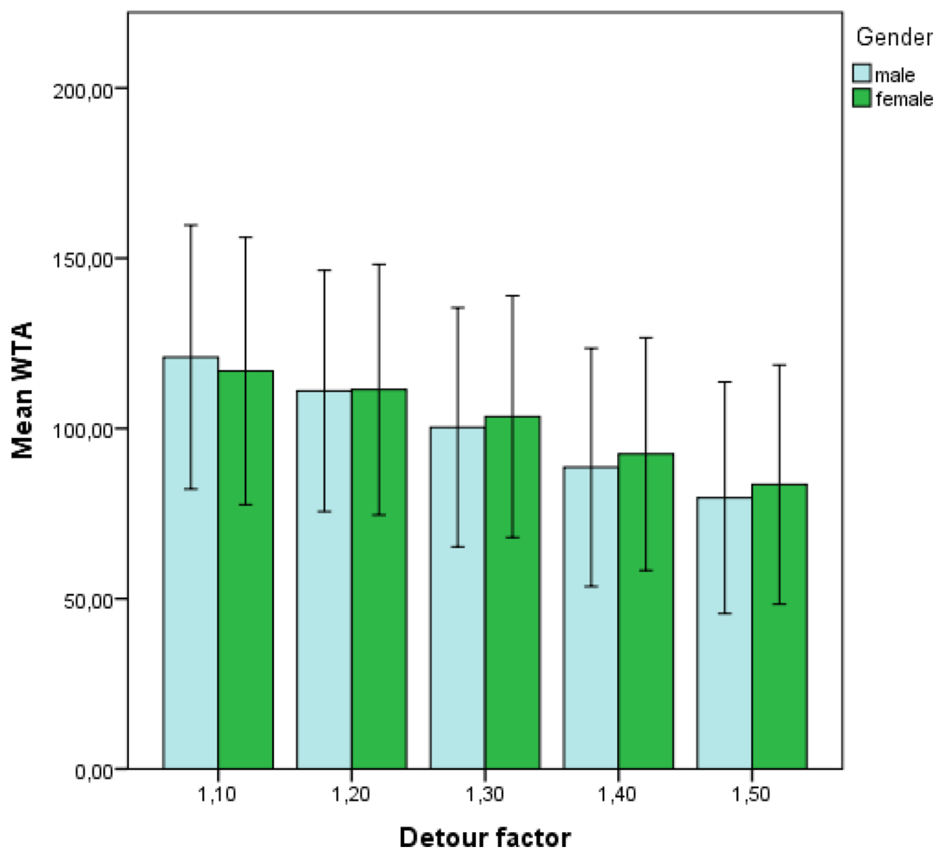

Fig. 8. Mean Willingness to Accept (WTA) depending on detour factor and gender. Whiskers represent +/− 1 standard deviation.

demand systems with and without driver. As presumed, the detour caused by the access and egress of fellow passengers negatively correlated with the respondents' willingness to accept shared rides in SAMODS. The findings thus are in line with recent studies regarding non-autonomous shared mobility on demand systems (König and Grippenkoven, 2019; Zhang et al., 2016). Thus, in order to attract travelers to SAMODS the maximum detour should be limited as it severely affects the acceptability of sharing rides. The study thus confirms the findings of Krueger et al. (2016) that revealed the importance of service attributes for the adoption of SAVs.

The rather small effect of travel time on the rejection rate compared to the effect of the detour factor might be related to the zooming factors of the scenarios. As shown in Fig. 5, the zooming factor depends on the travel time of the presented ride. Thus, the zooming factor decreased with the travel time increasing. Hence, the 20-min-route might be perceived as long as the 10-min-route at first sight. The different zooming factor might contribute to the perception that there are no significant differences between the scenarios in terms of travel time. This potential optical bias should be taken into account for interpretation of the results. The effect of the zooming factor might be an explanation for the small influence of travel time on the refusal rate and the WTA compared to the detour factor. Thus, it seems reasonable that the effect of the factor travel time is supposed to be underestimated in this study. Yet, the presentation based on the zooming factor was deliberately chosen since the choice situation should be as naturalistic as possible which includes the adaption of the size of the image section.

The findings further give an indication that rides that go to the opposite direction than the direct route are more often rejected by travelers. The scenarios that were characterized by a large deviation from the direct route from A to B lead to the highest rejection rate of participants. Thus, it can be deduced from the findings that travelers strongly dislike detours heading the opposed direction. This relationship was independent of the detour time and the travel time, thus indicating that besides the objective measure of these two factors, another, more subjective and perceptual factor affected the choice behavior. The relevance of a perceptual component on the individual's choice behavior is not uncommon, it was also found as a 'perception bias' in studies on route choice (Tawfik et al., 2010; Vreeswijk et al., 2014). Providing detailed information on the alternatives is essential for studying realistic choice behavior in the context of route choice, but hardly to process for study participants (Hassan et al., 2019). Hensher and Johnson (2018) also write about the difficulty to measure how people perceive a situation or an attribute and emphasize the importance of the individual's perception of the presented alternatives. This finding is noteworthy for the design of routing algorithms for SAMODS. Routing algorithms should consider the fact that passengers dislike large derivations and therefore limit the proposed route's angle of deviation from the direct route to an acceptable degree. Yet, further research is needed to assess the range of deviation that is still accepted by the travelers and how the presentation of the route might influence the traveler's perception of the deviation.

Besides the overall willingness of the respondents to share rides with fellow travelers in SAMODS, the respondents' price sensitivity for shared rides was assessed. In more detail, the amount of money the study participants are willing to spend for a shared ride in an autonomous mobility on demand system was compared to a non-shared ride. The resulting Willingness to Accept (WTA) was analysed to assess the respondents' need for monetary discounts in order to prefer shared over non-shared rides. A regressions analysis proved that the WTA was predicted by the travel time and the detour factor. Respondents required higher discounts, expressed by a lower WTA, when travel time and detour increase. Accordingly, the amount of the discount for a shared ride in SAMODS should depend on the travel time and the additional travel time resulting from the detour. Thus to attract travelers to share rides in future SAMODS the pricing scheme should take the travel time and the detour, which is even more important, into account.

A cumulative distribution function revealed the respondents' price sensitivity depending on detour factor and travel time. It was shown that a discount of 50% of the non-shared price is needed to attract 90% of respondents if the introduced usage scenario is a 10 min ride. For a small detour of the factor 1.1 a discount of 50% is needed as an incentive to choose the shared ride. Yet, the required discount to attract a critical mass of 90% of travelers increases when travel time and detour factor further increase. Hence, a price of 26.7% of the non-shared price is necessary to incentivize travelers if the detour factor is 1.5. Based on the findings it is shown that the proposed price for a shared ride in SAMODS should depend on the travel time and the detour of the route to provide a sufficient incentive to travelers to choose the shared ride. The findings thus contribute to the study by Martinez et al. (2015) that proposed a discount scheme for a shared taxi service. Our study expands the findings by showing that an adaptable rather than a fixed pricing system might be more beneficial for encouraging travelers to share rides. Based on our results, a travel time and detour dependent pricing system might be a more promising approach to attract travelers than a fixed discount scheme as used by MyTaxiMatch (Betzholz, 2017). The pricing structure should be as simple as possible since consumers tend to disengage if the cost structure is perceived to be too complex (Litman, 2018). Regarding the findings of the present study it is proposed to base the pricing structure on the resulting detour. A further approach to encourage travelers to use shared mobility systems might be a system that pools small rewards and offers larger rewards after some time like the concept of *Payback* since Pluntke and Prabhakar (2013) had shown in a study regarding travel time shifts that small rewards are not sufficiently suitable to effectively encourage behavioral changes. Besides the pricing structure, the authors like to encourage research on other measures to incentivize travelers to share rides or to discourage non-shared rides, like gamification approaches (Kelpin et al., 2016; Gabrielli et al., 2013) and framing the pro-social and pro-environmental behavior as unselfish or altruistic (Ringhand and Vollrath, 2018).

Three sociodemographic variables made an important contribution to predicting the WTA. As proposed, the age of the respondents influences the size of discounts needed for choosing the shared alternative. Lower age was related to a higher WTA indicating that younger travelers demand fewer discounts for sharing a ride in SAMODS. The results thus confirm the findings of Fraedrich et al. (2016) that revealed greater openness of younger participants towards autonomous mobility on demand concepts and Gilibert et al. (2017) who found the highest intended use for shared ridehailing concepts among the youngest age group. In contrast, higher age correlates with a lower WTA, thus proving the findings that elderly showed a lower acceptability of autonomous public transport systems (Madigan et al., 2017; World Economic Forum, 2018).

Besides age, gender was a sociodemographic variable that affected the amount of discount needed to choose the shared ride. As expected, female gender was linked to a lower WTA indicating that higher discount are needed to attract women to choose the shared ride. This finding is in line with the study results of Fraedrich et al. (2016) who found men to be more open to autonomous mobility on demand systems. Furthermore, the presented findings support the results of Lavieri and Bhat (2018) that a reduced likelihood of women to choose the shared option in a study regarding an autonomous transport system. A possible explanation might be higher security concerns of women when using shared ridehailing services (Sarriera et al., 2017) and a lower perceived safety in driverless bus shuttles (Shalonen, 2018). This finding can possibly be traced back to the considerable share of women that states to be faced with frightening situations in their everyday mobility (Stark and Meschik, 2018) combined with the lack of the driver in SAMODS. Gender further affected the relationship between the detour factor and the WTA. It was shown that men were more attentive to high detours in a way that their WTA for the shared ride was significantly lower than women's WTA. Thus, it can be assumed that the negative effect of detours on the willingness to share the ride in SAMODS is particularly strong for men. The findings imply some points for the service design of future SAMODS. Gender related differences in the assessment of the concept of SAMODS should be considered for the design and operation of these transport systems. Further research is needed to examine preconditions of perceived safety of prospective users of SAMODS, especially women, and countermeasures to cope with fears of sharing a ride in such driverless public transport systems (Grippenkoven et al., 2019).

Contradictory to Anspacher et al. (2005) who found a higher willingness to pay for a demand-responsive rail feeder system for suburbanites, this study revealed no effect of place of residence on the willingness to use SAMODS. A possible explanation might be the size and the composition of the sample that consisted of a high share of young participants living in urban areas. Furthermore, the presented scenario was a trip to the city centre. Thus, no statement concerning a suburban or rural scenario can be made. Adding onto this, no statements can be made concerning the effect of income on the travelers' willingness to share rides in autonomous mobility on demand systems because the factor was excluded from analysis due to multicollinearity.

To conclude, the findings imply that the willingness to share rides in SAMODS highly depends on situational as well as personal characteristics, thus confirming the findings of Krueger et al. (2016). Therefore, the booking app should take this dynamic into account and meet these requirements by offering a personalization of the booking process. By providing travelers the opportunity to express their preferences in using SAMODS, for example concerning the maximum detour, the service concept of SAMODS is expected to achieve higher acceptance since personalization has proven to increase the users' performance expectancy of apps (Lee et al., 2012). By providing a customized booking service, SAMODS could react to individual needs, like higher safety needs of women or a lower acceptance of detours of men. Thus, a booking app that enables the input of individual preferences could contribute to the reduction of negative user experiences, like a long detour on the way to a business meeting.

The findings of this paper can be used as a foundation for making ridesharing in autonomous mobility-on-demand systems more attractive and thus contribute to the creation of business cases. The willingness to accept notion and the modelling of the compensation demands of travelers can complement dynamic ride-sharing matching algorithms. Since today's ridesharing and mobility-on-demand systems recurrently experience challenges in matching ride requests, referred to as *dial-a-ride problem* (Atasoy et al., 2015a; Najmi et al., 2017). The utility functions of choice models can benefit from the presented results by incorporating the dynamic detour and travel time dependent pricing structure. To conclude, existing mobility on demand systems as well as future autonomous services can exploit the results of this paper for complementing their service models and thus make the sharing of rides more attractive.

5. Limitations

Several limitations have to be regarded for interpretation of the results. Starting with the instruction, a possible shortcoming of the study might be the difficulty to create respondents' vision of the autonomous transport system even though they have not experienced the system before. Despite the restricted validity of online surveys for the study of futuristic products or services, several studies used online surveys to assess the prospective users' appraisal of autonomous vehicles (Alessandrini et al., 2014; Bansal et al., 2016; Fraedrich et al., 2016; Tussyadiah et al., 2017). The novelty of autonomous driving and the rapid dissemination of new mobility services demand for explorative and somewhat unconventional approaches, like analyzing online comments or media website articles to assess the public opinion of future transport systems (Fraedrich and Lenz, 2014).

The challenge of envisioning SAMODS was attempted to overcome by providing a detailed textual and figural description of the autonomous mobility-on-demand-system. Yet, it is unclear whether all respondents imagined the same operational concept. The high share of participants that did not correctly remember the introduced scenario and thus were excluded from further analysis (18.8%, $n = 35$) gives a further hint that the study's objective might be hard to picture for the participants. Thus, the findings should be interpreted under consideration of the restrictions of validity due to participants' limited ability to adequately imagine the possible interactions with the system as they have not had any real experiences yet (Nordhoff et al., 2016).

Furthermore, the way the alternatives were presented in the SP experiment contributes to restrictions of the method. First, the shared option was always shown on the right which could have affected the choice of the respondents. Furthermore, the findings indicate an effect of the zooming factors of the presented routes that could have affected the respondents' assessment of the travel time. Related to this, the chosen methodological approach should be carefully reflected as SPs and CV are related to a number of shortcomings. These are mainly related to the possibility of response biases, the challenge to process different alternatives in parallel (Hassan et al., 2019) and respondents ignoring constraints (Cuccia, 2003). Thus, in designing the CV survey the recommendations of the NOAA panel (Arrow et al., 1993) and more recent guides were regarded if possible (Johnston et al., 2017).

Another common methodological limitation of choice experiments lies in the challenge that some respondents attend to all attributes while others attend to only a subset which leads to biased estimates, referred to as non-attendance (Hensher et al., 2012). The issue of non-attendance has been reported in the field of transport (e.g. Swait, 2001; Hensher, 2008). In the case of this study, the attendance of only two factors – detour factor and travel time suggests that the chance of one attributes not being considered (is rather low in comparison to more complex discrete choice experiments. Yet, an analysis of the possible non-attendance effect by self-reporting (Campbell et al., 2011) or statistical analysis of observed response patterns (Scarpa et al., 2009) would have strengthened the results. Another common limitation of online is the self-selection of participants. Hence, the sample consisted of a high share of young and well-educated people. However it is worth mentioning that the study sample might be the target group of SAMODS in the first instance as stated by Fraedrich et al. (2016) and Krueger et al. (2016).

As another possible limitation, the repondents' perception of the reliability of the presented travel time was not assessed. Thus, no statement can be made concerning the question whether the respondents trusted the presented travel time or added a margin of uncertainty. Further research should therefore query the respondent's trust in the presented choices.

Furthermore, for interpretation of the results it should be kept in mind that the acceptability of new services or products and thus the willingness to pay or the willingness to accept highly depends on the study's context and design. Brownstone and Small (2005) revealed significant differences between the willingness to pay in the context of toll roads when comparing revealed preference and stated choice experiments. The presented results thus should be interpreted within the scope of the study's context and need further validation in real-world experiments and field studies.

5.1. Further research needs

Besides the mentioned research needs concerning ways to encourage travelers to share rides in SAMODS, several proceeding research questions arise as result of the interpretation of the study's findings. The findings regarding the effects of the zooming factor and the route deviation on respondents' willingness to share the ride indicate the relevance of the way the route is presented in the booking app. Hence, the question arises how the presentation of information concerning the proposed rides affect the traveler's choice for or against the shared ride. In how far could a comprehensive information provision and feedback about the service (e.g. detour, changes in departure and arrival time) could increase the transparency of the system and thus enhance perceived reliability of the service and trust (Hoff and Bashir, 2015). Does information provided about fellow travelers might reduce feelings of insecurity and increase the willingness to share rides in driverless public transport systems with strangers? Does information on the gender and age of passengers entering the car presented in the booking app enhance the perceived safety in SAMODS? In this context, the study of preconditions for the perceived safety of prospective users, of those driverless transport systems, especially the safety concerns of women, is seen as an important field of future research (Grippenkoven et al., 2019). How far could the provision of an online connection to a remote control centre in cases of an emergency, the in-vehicle design and the provision of comprehensive information on the ride reduce usage barriers?

The study at hand controlled for only two independent variables of the service concept of SAMODS – travel time and detour. Several other factors are supposed to affect the traveler's willingness to share rides in SAMODS. Since feelings of insecurity recurrently revealed to be an important concern of travelers' when imagining a ride in an autonomous public transport systems (Shalonen, 2018), the circumstances of the trip like the question if someone is traveling alone or with somebody known seems of great importance for the choice situation. Accordingly, the time of day when the ride is carried out is proposed to be an important influencing factor. Furthermore, the authors like to encourage research on the influence of different trip purposes, like commuter trips vs leisure trips on the travelers' acceptance of detours and thus the willingness to share rides in SAMODS.

As mentioned above, further research is needed concerning the effect of the direction of the shared ride depending on the direct route to the desired destination. An interesting question arises concerning the degree of deviation from the direct route that is still accepted by the travelers. Again, the way the shared ride and the ride characteristics, like the resulting detour, are presented in the booking app seems to be of paramount importance for the design and operation of SAMODS. In this context, the personalization of the booking app opens a new area for further research. Which service characteristics should be eligible for customizing?

As another starting point for future research, we recommend the combination of stated and revealed preference techniques. Since SP experiments are commonly validated with the help of revealed preference methods that assess observed choices, the findings of this study could be reflected in the light of the actual choice behavior. Yet, as SAMODS are still not introduced to the market, data collection will be challenging. Hence, innovative research methods, such as wizard-of-oz techniques are needed (Schieben et al., 2009).

6. Conclusions

The Willingness to Accept (WTA) of sharing rides was assessed with the help of an online survey in a German population of $N = 150$. Results underline the importance of the travel distance and the detour factor for participants' willingness to share rides. Long travel times and high detour factors are shown to be relevant usage barriers for shared autonomous mobility on demand systems. Respondents required higher discounts, expressed by a lower WTA, when travel time and detour increase. The travel time added to the direct travel time to serve other passengers was a greater barrier to the use of SAMODS. Travelers show high rejection rates if the ride goes in the opposite direction. To conclude, the study provided several new insights into travelers' willingness to share rides with strangers in shared autonomous mobility on demand systems. Still, the study represents merely a first step to approach the new topic of sharing rides in autonomous public transport systems. The model's explained variance of 31.9% indicates that further factors need to be considered to increase our understanding of the facilitating factors in and barriers to the concept of SAMODS.

CRediT authorship contribution statement

Alexandra König: Conceptualization, Methodology, Data curation, Writing - original draft, Visualization, Writing - review & editing. **Jan Grippenkoven:** Writing - review & editing, Project administration, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Attachment D - Publication 4

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A.K. provided the research idea.

A.K. prepared these samples

C.W. supported in the literature review.

A.K. developed the stated preference study

A.K. designed / planned / executed the study

C.W. participated in the methodological discussions

J.G. gave research assistance.

J.G. gave methodological advice.

A.K. conducted the measurements.

C.W. took part on the data collection.

A.K. analyzed the data

J.G. supported the data analysis.

A.K. wrote the manuscript.

J.G. contributed to writing and improving of the manuscript.

C.W. contributed to writing and improving of the manuscript.

J.G. contributed to revising the manuscript.

A.K. supervised the project.

J.G. gave scientific advice / constructive feedback

sustainability

Article

Generation Y's Information Needs Concerning Sharing Rides in Autonomous Mobility on Demand Systems

Alexandra König [1,*], Christina Wirth [2] and Jan Grippenkoven [1]

[1] German Aerospace Center, Institute of Transportation Systems, 38108 Braunschweig, Germany; jan.grippenkoven@dlr.de
[2] SRH Hochschule der Populären Künste (HDPK), 10783 Berlin, Germany; christina.wirth@t-online.de
* Correspondence: alexandra.koenig@dlr.de; Tel.: +49-531-295-3676

Abstract: Empirical studies show that autonomous vehicles can contribute to sustainability goals when rides are shared. However, sharing rides with strangers in shared autonomous mobility-on-demand systems (SAMODSs) might impede the adoption of these systems. The present study addresses the research question whether a comprehensive information provision about fellow passengers could increase acceptability of the shared rides in SAMODSs. A discrete choice experiment (N = 154) assessed the potential of different levels of information on fellow passengers: (1) no information, (2) name, (3) picture, (4) rating, (5) combination of name, picture and rating. The results show that the overall compensation demands for sharing a ride was a reduction of approximately 25% of the nonshared reference price. The provision of detailed information about fellow travelers proved beneficial for reducing the compensation demands of travelers while the provision of a name only resulted in higher compensation demands. A significant effect of the fellow passengers' gender indicated that male gender information was related to a higher refusal rate than female gender information. This was particularly relevant when only names were presented. The study provides first empirical insights into the psychological factors concerning the emerging trend of shared mobility.

Keywords: ridesharing; user requirements; information needs; trust; gender perspective; perceived safety; automated and connected transport

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1. Introduction

1.1. Shared Autonomous Mobility on Demand Systems

Driverless vehicles of SAE level 5 [1] that are capable of self-driving under all conditions [2] are predicted to be a promising future because they will most probably contribute to a transition towards a more efficient, safe and convenient transport system [3–5] and are supposed to fundamentally change the way we travel and live [6]. Studies suggest that the value of time in terms of willingness to pay for saving travel time might decrease because people can use the time in the autonomous vehicle (AV) for other purposes than driving [6]. Depending on the scenario, the penetration of AV traffic will either dramatically rise or significantly decrease [4,5,7]. Privately-owned autonomous vehicles are expected to contribute to an increase in vehicle kilometres travelled (VKT) and, consequently, higher local emissions: "If autonomous vehicles turn out to be mainly privately owned, the resulting increase in road traffic will negate the time savings" [6] (p. 9f). In contrast, shared autonomous vehicles will contribute to a decrease in VKT, parking spaces and emissions [4,5,7]. Thus, research requests to increase the occupancy rate of AV by ridesharing, which is considered as an essential prerequisite for reducing the traffic volume [8–12]. Lavieri and Bhat (2018) stated "there is growing evidence that ridesharing will be a key element to ensure a sustainable future to urban transportation in an AV future." [10] (p. 29). Ridesharing in autonomous vehicles can be realized by using a demand-responsive operation scheme of so-called mobility-on-demand systems that allows for flexible and highly dynamic adoptions of the route according to the passengers' requests [13]. The combination of autonomous driving technology and mobility-on-demand systems is considered to be a beneficial synergy for reaching sustainability goals [3]. The paper defines shared autonomous mobility-on-demand systems (SAMODSs) as autonomous, shared public transport services with flexible routing, which implies additional journey time due to the pick-up and drop-off of other passengers. See [14] for a more detailed description of different ownership and usage scenarios of shared autonomous vehicles.

The interest in SAMODSs, also called SAMS [15], is reflected in the considerable number of simulation studies assessing the economic and ecological effects of shared driverless mobility-on-demand systems [16] as well as impacts on transport systems and traffic [9,17–19]. From the passenger's perspective, the ridesharing aspect of mobility-on-demand systems is likely to be a crucial point for users' assessment of the service because the sharing of rides implies detours for passengers [20]. Furthermore, the absence of a driver in SAMODSs was shown to be related to higher safety concerns [21,22]. Accordingly, Krueger, Rashidi, and Rose (2016) state that the adoption of SAMODSs "[. . .] heavily relies on user acceptance, as users must be willing to spend some time with a stranger in the confined space [. . .]." [23] (p. 345).

Giving regard to the expected benefits of SAMODSs for reaching sustainability goals in transport, the factors that affect the willingness of future users to adopt these systems must be considered in the design of these systems. The present study aims to identify facilitating factors for travellers' willingness to share rides with strangers in SAMODSs. More specifically, the study's objective is to assess the effectiveness of information provision about fellow travellers to improve travellers' willingness to use the service.

1.2. Literature Review

Scientific literature on the acceptance of self-driving public busses (SDPB) sharply increased in the last years [22,24–26]. These studies prove the impact of attitudinal factors, such as the perceptions of safety on the acceptance of the new autonomous public bus system (e.g., [24]). The findings imply a rather controversial perception of potential users on the technology. On the one hand, studies by [22,27] report a high acceptability of self-driving vehicles for public transport use. On the other hand, several studies found considerable concerns among potential users towards the emergence of driverless vehicles and the transformation of public transport system [28,29]. The interest in autonomous vehicles for public transport is reflected by the number of pilot projects that tested autonomous public transport in naturalistic settings, like in Berlin, Germany [30] (Nordhoff et al., 2018), Espoo, Finland [22] or Lausanne, France [27]. However, it should be noted that the number of pilot studies in open and mixed traffic is quite limited, and thus, empirical evidence concerning the users' acceptance is restricted to specific characteristics of the pilots, like slow velocity and the presence of a trained fallback driver. In contrast, the use case of SAMODSs is challenged with additional degrees of freedom because the operation scheme depends on flexible on-demand routing rather than fixed schedules. However, as a consequence to their novelty, there are only few empirical studies addressing the users' acceptance of SAMODSs. As one of the first studies addressing the use case of SAMODSs, Fraedrich, Cyganski, Wolf, and Lenz (2016) found low acceptability of respondents for the so-called *Vehicle on Demand.* About two thirds of the respondents showed slight or strong unwillingness to use such shared autonomous transport systems [21]. Safety concerns and low perceived performance expectancy of SAMODSs were provided as possible explanations by the authors [21]. Accordingly, Lavieri and Bhat (2018) found the adoption of SAMODSs to be strongly associated with the increased travel time due to the access and egress of further travellers [10]. The study furthermore showed that privacy and security concerns discouraged participants to choose shared rides. The results of the study further indicated that sharing trips with strangers seems to be less aversive for commute trips than for leisure trips [10].

A stated choice survey by Krueger, Rashidi and Rose (2016) found the service attributes waiting time, travel time and costs to be important determinants of the willingness to use SAMODSs [23]. The findings are supported by a discrete choice experiment that proved a strong effect of travel time and the detour, caused by the pick-up and drop-off of passengers, on participants' willingness to share rides in SAMODSs [31]. The authors conclude that a pricing system of SAMODSs should pay attention to ride-specific travel time and detours in order to attract travellers to choose the shared option [31].

Concerning the individual-specific determinants of acceptability, the above-mentioned stated choice survey by Krueger, Rashidi, and Rose (2016) found individuals between 24 and 29 years to be the most open to choose the shared ride in SAMODSs [23]. Thus, in line with similar studies, it can be assumed that younger generations are likely to be the first users of such services [32,33]. König and Grippenkoven (2020) found that a higher discount is needed to attract women to choose the shared ride compared to men [31]. The finding is supported by the results of Lavieri and Bhat (2018) who found a reduced likelihood of women to choose the shared option [9]. This finding might be explained by another finding, that women are supposed to have stronger safety concerns in driverless bus shuttles than men [34].

The findings of [23] were complemented by a recent study that used a stated preference experiment to assess users' willingness to share rides with strangers in shared autonomous vehicles [35]. The study found a considerable reluctance of women to choose the shared option when sharing the ride with a male co-traveller [35]. The authors thus encourage research and policy to identify solutions for enhancing women's experiences with shared automated transport services [35].

Drawing on studies that address ridesharing systems, like BlaBlaCar [36], can provide indications for the underlying determinants of sharing rides in SAMODSs. These studies recurrently report individuals' unwillingness and resistance to share rides with strangers due to the need for sufficient personal space, the possibility of having a negative social interaction, distrust as well as safety and security concerns [10,37–39]. Morales Sarriera et al. (2017) also report on riders' feelings of prejudice towards other passengers due to their race or socio-economic class [38]. Substantial discrimination in the context of ridesharing was also reported in a recent experimental study by [40]. They found empirical evidence for the discrimination of Turkish men in a study with German users of a ridesharing service [40]. The unwillingness to share rides with strangers is most likely associated with a lack of trust [37].

Providing information about fellow passengers might possibly enhance trust [38]. The willingness to share rides correlated with the name recognition of the fellow travellers in a study by [41]. Thus, travelling with a friend of a friend or a member of their university resulted in a higher willingness to share the trip than travelling with an unknown person. Bansal et al. (2016) comes to similar conclusions as they found that more than half of the respondents are willing to share the ride with a friend of a *Facebook* friend although he or she was not directly known to them [42]. Moreover, Siddiqi and Buliung (2013) suggest providing various personal information such as name, age, gender and occupation about other passengers for ridesharing service [43]. They also recommend providing a peer-reviewed reputation system [43]. However, for the use case of SAMODSs, empirical findings are lacking regarding the question whether information provided about fellow travellers might reduce feelings of insecurity and increase the willingness to share rides with strangers.

1.3. Research Objectives

The present study aims to examine the effect of four potential determinants on the willingness to share rides with fellow travellers in SAMODSs and their potential interplay: (1) travel time, (2) degree of vehicle automation, (3) quality of information on fellow passengers (e.g., picture, name or rating) and (4) gender of the fellow passenger. In particular, the study addresses the following research questions:

- RQ1: How far does the provision of information about fellow travellers affect the willingness to share rides in mobility-on-demand systems?
- RQ2: Which information on fellow passengers (e.g., picture, rating etc.) proves especially relevant for increasing travellers' willingness to share rides in mobility-on-demand systems?
- RQ3: Do the information needs of travellers increase when no driver is present in autonomous mobility-on-demand systems?
- RQ4: Does the length of the trip influence the relevance of provided information about fellow passengers for travellers' willingness to share the trip? Figure 1 provides a schematic overview over the research questions and the expected relationships between the variables. The study at hand thereby focuses on a specific potential user group—Generation Y, which comprises persons born between 1981 and 1999, also called *millennials* [44]. This specific cohort is expected to be more likely to adopt mobility-on-demand like Uber services [32], tend to favor sharing-based service models over private ownership [33] and show greater openness towards autonomous mobility services [21].

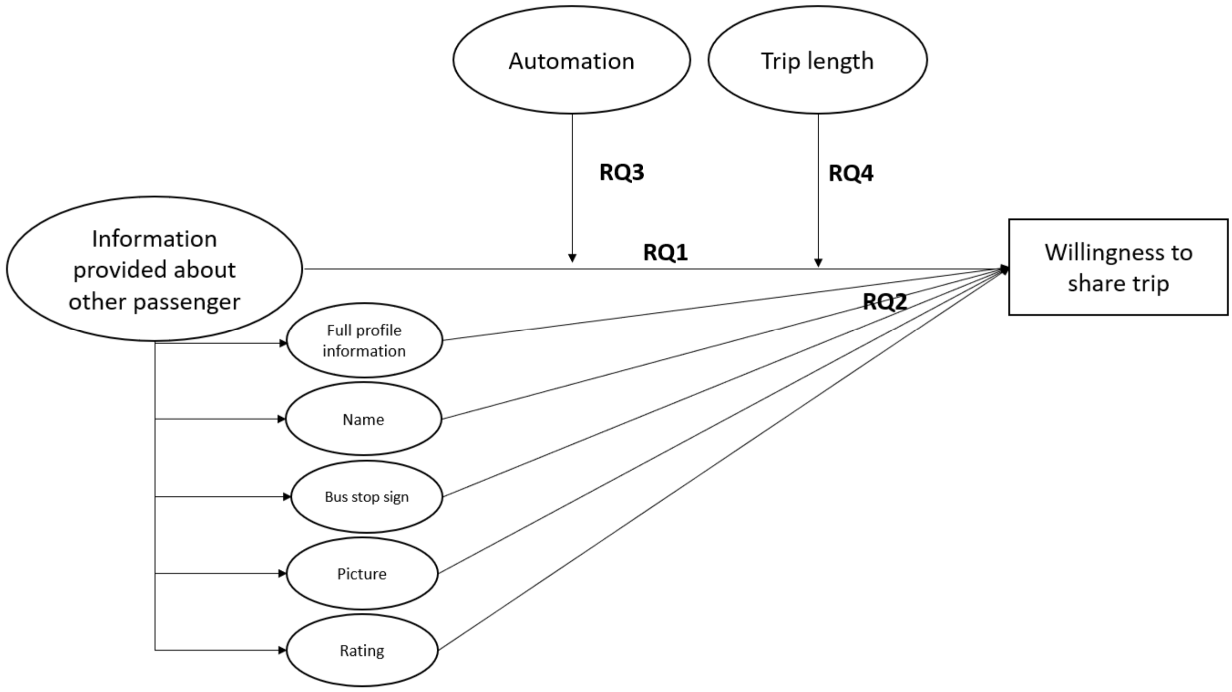

Figure 1. Schematic representation of the research questions. Dependent variable is represented as a rectangle, predictors and mediators as ellipses.

2. Materials and Methods

2.1. Study Design

A discrete choice experiment (DCE) was used for approaching the research questions [45]. DCE are frequently used in transportation research [46] and has been applied to the assessment of acceptability of autonomous vehicles before [47,48].

The dependent variable was the amount the respondents are willing to spend for a shared ride in an autonomous mobility-on-demand system compared to a nonshared ride. The willingness to share rides was realized as the Willingness to Accept (WTA). The WTA is defined as the amount a person is willing to accept to abandon a good or to put up with something negative and thus is linked to the concept of willingness to pay (WTP) that refers to the maximum price an individual is willing to pay for a product of service [49]. The WTA was assessed by the amount respondents are willing to pay for a shared ride in an SAMODS compared to the reference of a nonshared ride.

Inspired by studies that studied the effect of the presentation of different information on the acceptance of ridesharing, like pictures [10,38], name [43] or a rating [38,39,43], the study used *quality of information* as the first independent variable. Quality of information had five levels: (A) *bus stop sign*, (B) *name*, (C) *picture*, (D) *rating* and E) *full profile information* as a combination of the levels *name*, *picture* and *rating* (Figure 2). Further independent variables were (1) *gender*: information on the gender of the further traveller, (2) *travel time*: the length of the ride with two levels: 14 min vs. 25 min and (3) *automation*: the level of vehicle automation: with driver vs. driverless (Figure 1). The profile pictures of the female and male fellow travellers were used from the CHICAGO FACE DATABASE with a medium rated attractiveness [50]. Typical German female (Michaela) and male (Andreas) names were chosen for the SP experiment. A mixed design was used, consisting of the between-subjects factor automation and the within-subject factors quality of information, travel time and gender of the fellow traveller.

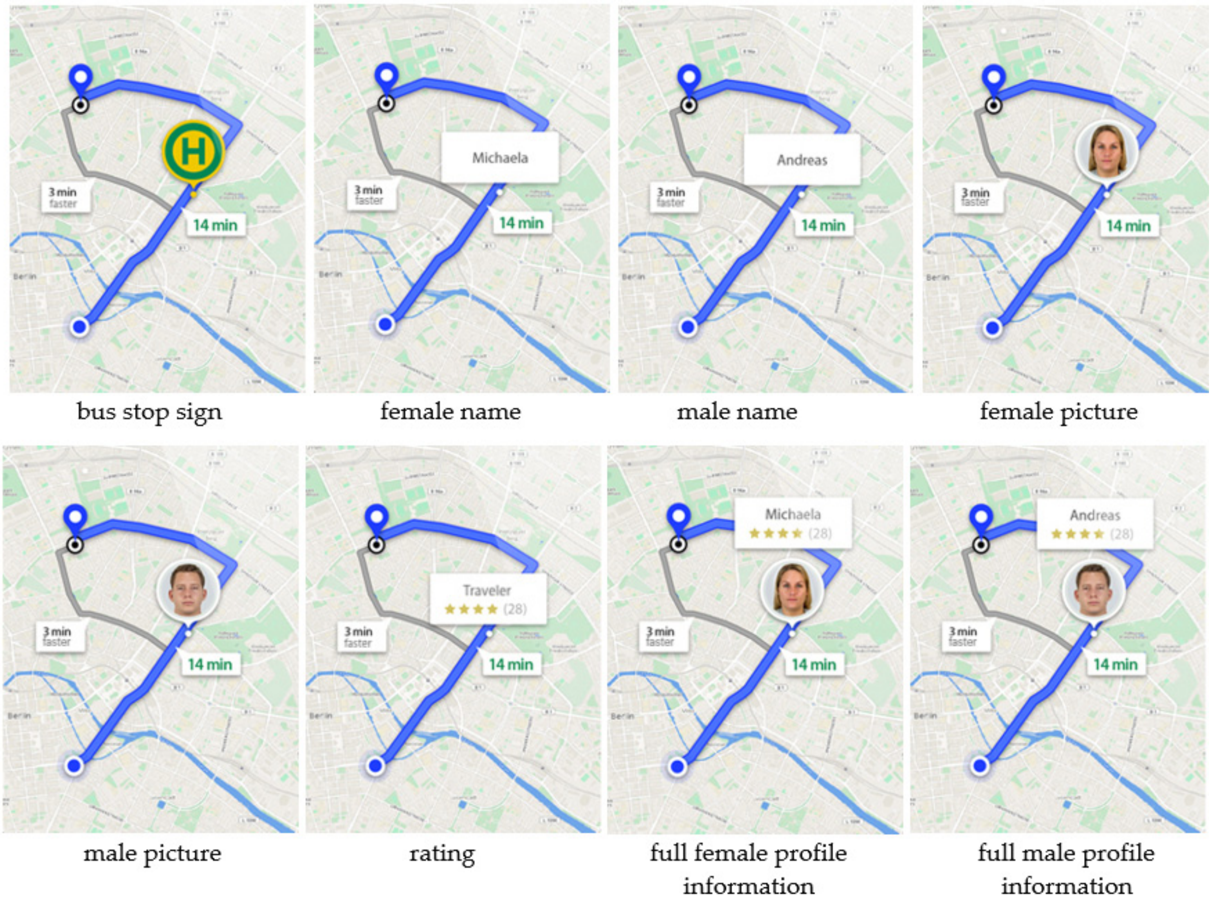

Figure 2. Levels of the variable quality of information.

Two alternative routes were presented to the study participants: (1) a direct, nonshared ride and (2) a shared ride implying a detour caused by the access of a fellow traveller (Figure 3). The shared scenarios were created based on the assumption that the respondents share about 50% of travel distance together. For each scenario, the study participants were asked to imagine a ride with only one fellow passenger. In order to assess the WTA for shared rides, the participants were asked to specify the maximal amount of money they would be willing to pay for the shared ride (right) in comparison to the nonshared ride (left). The fictional currency ð was used for avoiding anchoring effects of current prices for transportation. Respondents were further given the chance to choose the alternative "I would rather not choose option 2" as an opt-out alternative.

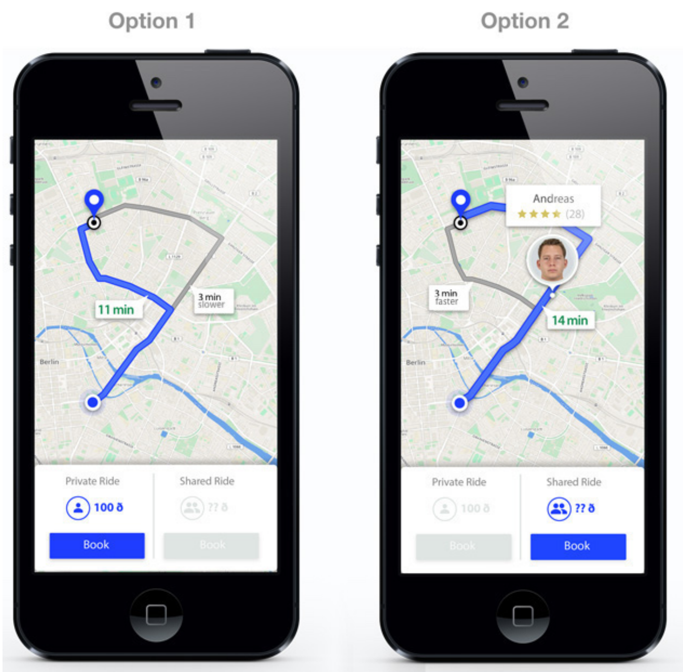

Figure 3. Example of a choice set consisting two alternatives: left: nonshared ride, right: shared ride with full information on fellow traveller.

2.2. Procedure

The study was performed as an online survey using the software SosciSurvey [51]. The participants were recruited via social media platforms during August and September 2019. The respondents were randomly assigned to either the scenario based on a mobility-on-demand system with or without a driver. The participants were introduced to the study subject by a textual and graphical explanation regarding the vehicle concept, which was introduced as an 8-seater. Following a between-subjects design, half of the participants were introduced to the operational concept of an autonomous mobility-on-demand system whereas the other half was introduced to the concept with driver. They were then introduced to the task of determining the maximum price they are willing to pay to accept sharing rides with strangers. For this purpose, two examples were presented to the participants. Right before the start of the choice tasks the scenario was presented to the participants. The scenario was framed as a ride in an urban setting with the objective to meet a friend.

The participants were asked to respond to 16 choice tasks as presented in Figure 3. The order of the choice tasks varied between the participants. At the end of the questionnaire, the respondents were asked to answer several sociodemographic questions and questions regarding their mobility behavior. Furthermore, trust in fellow travellers was measured with the help of three items adapted from a questionnaire study concerning ridesharing: "I would trust fellow passengers", "I believe I would have concerns regarding my safety when sharing a ride" and "For me, sharing rides with fellow passengers is not accompanied with risks" [37]. A five-point Likert scale was used for answering the items.

2.3. Data Analysis

Data were analysed with the help of the statistical software SPSS. Only those respondents of the survey were included that were aged between 18 and 39 and thus were assigned to the Generation Y [52]. Respondents were excluded from data analysis (n = 39) when they did not correctly remember the introduced scenario (Do you remember which of the following scenarios was introduced to you?).

For data analysis, the format of the dataset was restructured from wide to long format. For computing the WTA, the amount that participants were willing to pay for a shared ride

($ð_{shared}$) was related to the default price of the nonshared ride ($ð_{nonshared}$). The resulting percentage ($WTA_{shared} = ð_{shared/}ð_{nonshared}$) was used for further analysis of the WTA.

2.4. Participants

The final sample (*N* = 154) was characterized by a mean age of 26.5 years (*SD* = 4.4 years). The sample consisted of more women (*n* = 95, 61.7%) than men (n = 57, 37.0%, rest missing). The majority of respondents were still in education (57.1%). A share of 31.8% worked full-time and another 6.5% in part-time. As shown in Table 1, the respondents were well educated, with more than 50% holding a university degree. The net household income was comparable to the general population aged 18–25 (1.779 €) and 25–35 years (2.965 €) [53]. A total of 94.8% had a driver's license (*n* = 146). The bike was the most often used transport means on a regular basis for 48.7% of respondents (*n* = 75).

Table 1. Sociodemographic characteristics of the sample (*N* = 154).

Sociodemographic Variable	Characteristics	n (%)
Size of residence (number of inhabitants)	<5.000	17 (11.0)
	5.000–50.000	19 (12.3)
	50.000–500.000	72 (46.8)
	> 500.000	45 (29.2)
	Missing	1 (0.6)
Highest educational level	Secondary school certificate	1 (0.6)
	High school graduation	42 (27.3)
	Vocational training	9 (5.8)
	University degree	98 (57.1)
	PhD-degree	2 (1.3)
	Missing	1 (0.6)
Job status	Full-Time	49 (31.8)
	Part-Time	10 (6.5)
	In education	88 (57.1)
	Temporary out of work	1 (0.6)
	Unemployed	1 (0.6)
	Missing	5 (3.2)
Net household income	<1.000 €	57 (37.0)
	1.000–1.500 €	25 (16.2)
	1.500–2.000 €	17 (11.0)
	2.000–3.000 €	32 (20.8)
	>3.000 €	15 (9.7)
	Missing	8 (5.2)
Share of transport mode (at last once a week)	Car	24 (15.6)
	Bus	35 (22.7)
	Tram/subway	49 (31.8)
	Train	24 (15.6)
	Bike	75 (48.7)

3. Results

In the following, the results of the data analysis are presented for the effects of the four independent variables: travel time, degree of vehicle automation, quality of information on fellow passengers (e.g., picture, name or rating) and gender of the fellow passenger.

3.1. Refusal Rate of Shared Rides

First, data was analyzed concerning the rate of respondents that rejected the shared rides by indicating "I would rather not choose option 2". The refusal rate was implemented as the percentage of shared rides that were rejected by the respondents. The overall refusal rate across all levels of information provision was 2.7% (*SD* = 1.6%). As shown in Table 2, the mean refusal rate differed depending on the amount of information given about the other passengers. The refusal rate was the highest under the condition of *25min_name_male* with a refusal rate of 7.1% (*SD* = 0.26%) and the lowest for the condition *14min_all_female* with not a single rejection (0%). The descriptive analysis reveals that the share of rejected rides is slightly higher for longer rides (Mean refusal $rate_{25min}$ = 3.7%, *SD* = 0.19%, Mean refusal $rate_{14\ min}$ = 1.7%, *SD* = 0.13%).

Table 2. Mean refusal rate in percent and standard deviation in parentheses according to information quality (bus stop sign, name female, name male, picture female, picture male, rating, full profile information female and full profile information male) and travel time (14 min vs. 25 min).

		Level of Quality of Information								
		BSS	**N_F**	**N_M**	**P_F**	**P_M**	**R**	**F_F**	**F_M**	**Total**
Share of rejected shared rides in %	14 min	1.9 (0.14)	1.9 (0.14)	4.5 (0.21)	1.3 (0.11)	2.6 (0.16)	0.6 (0.08)	0.0 (0.00)	0.6 (0.08)	1.7 (0.13)
	25 min	5.2 (0.22)	1.3 (0.11)	7.1 (0.26)	1.9 (0.14)	3.2 (0.18)	3.9 (0.19)	3.2 (0.18)	3.2 (0.18)	3.7 (0.19)

Note. BBS = bus stop sign, N_F = name female, N_M = name male, P_F = picture female, P_M = picture male, R = rating, F_F = full profile information female, F_M = full profile information male.

For modeling the effect of the independent variables on the binary dependent variable *refusal rate*, a Generalized Linear Mixed Model (GLMM) was computed with the statistical software *R* using the function *glmer* of the package *lme4* [54]. GLMM allow for the estimation of longitudinal data—like repeated observations in the case of the study—and are applicable to non-normal data [55]. The categorial variable *information degree* was transformed in dummy-coded variables with the category *bus stop sign* as baseline.

For model 1 with main effects only, the regressors *travel time*, *gender information* and the two dummy variables for *full profile information* and *rating* revealed significance in the model (Table 3). The *degree of vehicle automation* and the information levels *name* and *picture* failed to reach significance within the model. The model concerning the null hypothesis revealed an intraclass correlation (ICC) of. 608, indicating that more than 60 percent of variation in the respective variables is between people and the answers given by people in the repeated measures were rather stable [56].

To test the effects of the moderator variables on the dependent variable, an interaction model was computed. For the interaction model, interaction terms were included based on the assumptions guided by the research questions (Section 1.3) if they increased model fit. Excluding the variable *degree of automation* from the model, increased model fit. The final interaction model (Table 3, right) had a better model fit than model 1 (−2LLog = −193.3, AIC = 404.5, BIC = 456.8). Thus, it can be concluded that the interaction model is more suitable to reflect the data.

As shown before in Model 1, travel time had a significant effect on the refusal time in a way that a one unit increase in travel time was associated with a 1.148 unit increase in the expected log odds of the refusal rate ($p < 0.001$). In contrast to model 1, the predictors rating, full profile and gender information become less important in the interaction model. The presentation of full profile information significantly decreased the probability of refusing a shared ride (*exp*(*ß*) = 0.407, $p = 0.050$). In contrast, providing information on the name of the fellow passenger increased the refusal rate (*exp*(*ß*) = 16.44, $p = 0.024$). The presentation of a male name increased the respondents' unwillingness to share rides while the presentation of a female name improved the willingness to share rides and was linked to a reduced the refusal rate as shown by a marginally significant effect (*exp*(*ß*) = 0.256, $p = 0.087$). The model further proved the relationship between the refusal rate and the presentation of gender information in a way that male gender information was related to a higher refusal rate than female gender information, (*exp*(*ß*) = 0.394, $p = 0.043$).

Table 3. Comparison of the Generalized Linear Mixed Models.

	Model 1					Model 2–Interaction Model				
Predictors	*ß*	*exp*(*ß*)	*SE*	*z-value*	*p*	*ß*	*exp*(*ß*)	*SE*	*z-value*	*p*
Intercept	−8.895	<0.001	1.071	−8.307	<0.001 **	−10.304	<0.001	1.12	−9.167	<0.001 **
Travel time	0.104	1.109	0.032	3.204	0.001 **	0.138	1.148	0.041	3.393	<0.001 **
Automation (with driver = 0)	−0.597	0.550	0.901	−0.662	0.508	–	–		–	–
Dummy_name	−0.032	0.969	0.477	−0.067	0.947	2.800	16.44	1.242	2.254	0.024 **
Dummy_picture	−0.770	0.463	0.509	−1.518	0.129	–	–	–	–	–
Dummy_rating	−1.206	0.299	0.585	−2.062	0.039 **	−0.927	0.396	0.555	−1.67	0.095 *
Dummy_full profile	−1.222	0.295	0.537	−2.276	0.023 **	−0.898	0.407	0.459	−1.958	0.050 *
Gender information (male = 0)	−1.079	0.340	0.389	−2.776	0.006 **	−0.932	0.394	0.46	−2.024	0.043 **
Dummy_name × Gender information						−1.364	0.256	0.796	−1.714	0.087 *
Dummy_name × travel distance						−0.113	0.893	0.070	−1.621	0.105
−2LLog			−196.5			−193.3				
AIC			411.0			404.5				
BIC			463.3			456.8				

Note. AIC = Akaike information criterion, BIC = Bayes criterion, * $p < 0.1$, ** $p < 0.05$.

3.2. Willingness to Accept

Disregarding the independent variables, the overall WTA was 73.73% of the nonshared reference ride. The variance of the WTA was high as shown by *SD* = 17.17%.

The descriptive analysis reveals that the WTA is slightly higher for shorter rides of 14 min (*M* = 74.17%; *SD* = 19.02%) than for longer rides of 25 min (*M* = 68.91%; *SD* = 24.03%). As shown in Figure 4, the mean WTA differed according to the quality of information presented about the fellow passenger. The mean WTA was the lowest under the condition of 25min_bus stop sign (*M* = 67.12%, *SD* = 25.63%) and the highest for 14min_full profile information (*M* = 76.14%, *SD* = 17.20%).

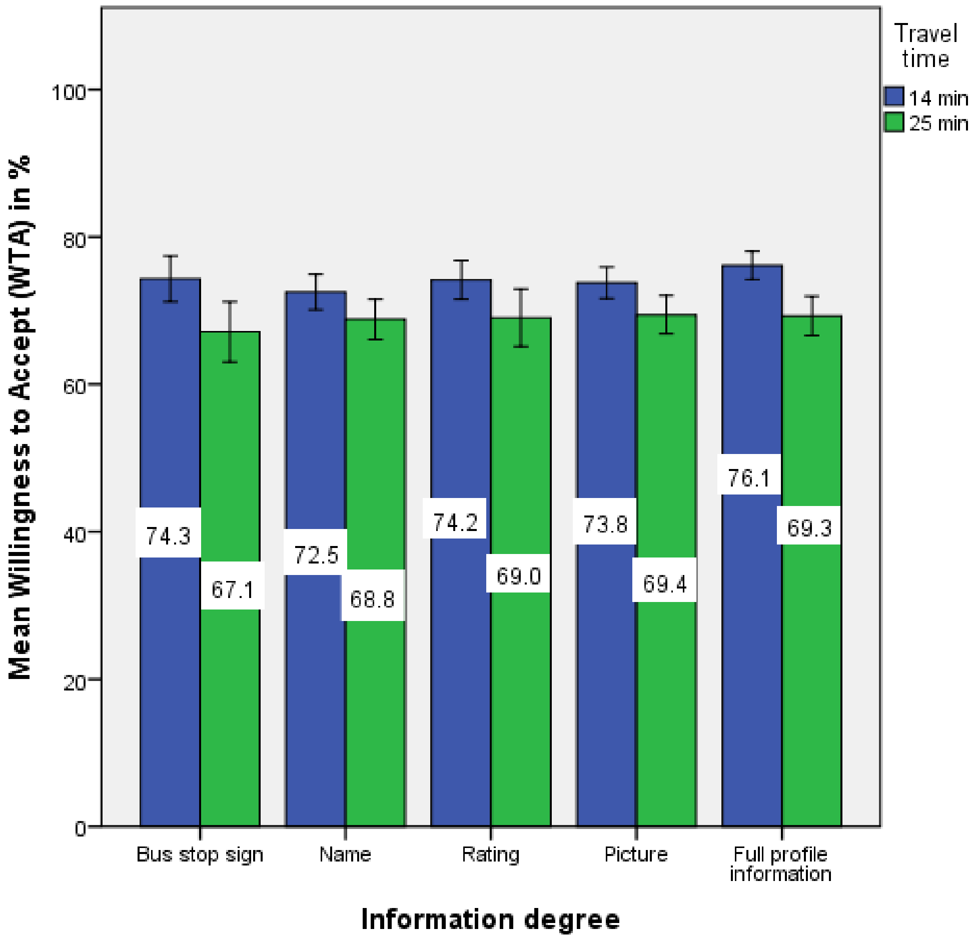

Figure 4. Mean Willingness to Accept according to information degree and travel time. Whiskers represent confidence intervals.

With regard to gender information, a significant effect of the gender of the fellow passenger on the WTA was shown under the condition name ($t(614) = -1.859$; $p = 0.064$, Figure 5). In more detail, it was shown that the presentation of the female name was related to a higher WTA (*M* = 72.40, *SD* = 20.38) than the presentation of a male name (*M* = 68.96, *SD* = 25.22).

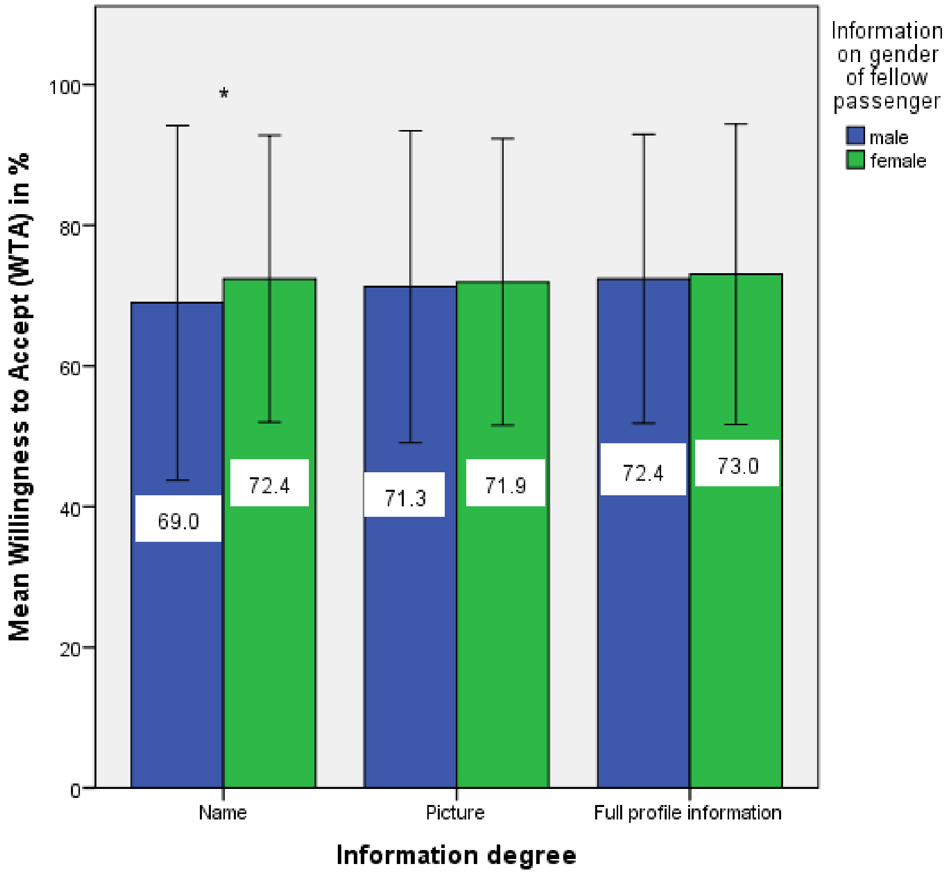

Figure 5. Mean Willingness to Accept according to information degree and gender of fellow passenger. Whiskers represent +/− 1 *SD*, * $p < 0.1$.

A mixed-effects model was computed using the function *lmer* of the *lme4* package of *R* [55]. The categorial variable information degree was transformed in dummy-coded variables with the category bus stop sign as baseline. First, a model with main effects only was computed. Then, interaction terms were added to the model.

As shown in Table 4, regression analysis proved a highly significant effect of *travel time* on WTA ($t(9) = -0.519$; $p < 0.001$). Respondents showed higher WTA values when trip duration was short ($M = 74.17\%$; $SD = 19.02\%$) than for longer rides ($M = 68.91\%$; $SD = 24.03\%$).

Concerning the effect of the degree of vehicle automation the regression analysis found a marginally significant effect in the model in a way that vehicle automation was linked to a lower WTA ($t(148.99) = 5.093$; $p = 0.066$), thus indicating that respondents require less compensation when the vehicle is autonomous.

Information on the gender of the fellow passenger marginal significantly predicted the WTA ($t(9.00) = 1.459$, $p = 0.062$). According, as shown by *exp(ß)*, the WTA increased by 10.794 when female instead of male gender information were presented.

Subsequently, interaction terms were added to the interaction model. The model was chosen that reached the best model fit (−2LLog = 9921.6, AIC = 19,865, BIC = 19,929). The change in −2LL between the two models (−LLogModel1 = −9923.2, −2LLogModel2 = 9921.6) was highly significant ($p < 0.05$) according to the critical values of the chi-square distribution [48].

Table 4. Comparison of the Linear Mixed-Effects Models.

	Model 1					**Model 2–Interaction Model**				
Predictors	*ß*	*exp*(*ß*)	*SE*	*t*	*p*	*ß*	*exp*(*ß*)	*SE*	*t*	*p*
Intercept	76.317	1.393	2.312	33.014	<0.001 **	76.777	2.207	2.177	35.28	<0.001 **
Travel time	−0.519	0.519	0.059	−8.756	<0.001 **	−0.519	0.595	0.054	−9.606	<0.001 **
Automation (with driver = 0)	5.093	162.88	2.751	1.851	0.066 *	5.093	162.88	2.751	1.851	0.066 *
Dummy_name	−0.435	0.647	1.084	−0.401	0.698	−1.765	0.171	0.915	−1.929	0.005 **
Dummy_picture	0.370	1.448	1.084	0.341	0.741	–		–	–	–
Dummy_rating	1.154	3.171	1.187	0.972	0.356	0.694	2.001	0.915	0.759	0.448
Dummy_full profile	1.587	4.889	1.084	1.464	0.178	1.447	4.250	0.709	2.042	0.041 **
Gender information (male = 0)	1.459	4.302	0.685	2.129	0.062 *	0.819	2.268	0.709	1.157	0.247
Dummy_name × Gender information						2.379	10.794	1.294	1.840	0.066 *
−2LLog			−9923.2					−9921.6		
AIC			19,868					19,865		
BIC			19,932					19,929		

Note. AIC = Akaike information criterion, BIC = Bayes criterion, * $p < 0.1$, ** $p < 0.05$.

In the interaction model, the main effect of degree of automation was still marginally significant ($p = 0.066$). Interactions terms with degree of automation and other factors did not reach significance and did not improve model fit and thus were not included in the revised model.

Travel time revealed a highly significant negative effect on the WTA ($ß = -0.519$, $p < 0.001$). As shown by $exp(ß) = 0.595$, a one unit increase in travel time was associated with a 0.595 unit decrease in the expected log odds of the WTA ($p < 0.001$).

Quality of information revealed to be a significant predictor only for full profile information ($t(2258.99) = 1.447$; $p = 0.041$). The regression analysis thus showed that the WTA significantly increased ($exp(ß) = 4.250$) when full profile information was presented compared to the baseline condition bus stop sign. On the contrary, the presentation of information on the name of the fellow traveler revealed a significant and negative effect on the WTA ($ß = -1.765$, $p = 0.005$), showing that information concerning the name alone increased the compensation demands. An interaction effect with the gender of the fellow traveller with the presentation of a name was shown ($t(2258.99) = 2.379$; $p = 0.066$). In comparison to model 1, the predictor gender information became less important in presence of the interaction term name x gender information in the interaction model.

An ANOVA with repeated measures proved a significant interaction effect of gender information and gender of the respondents under the condition *picture* for the longer ride ($F(1,142) = 5.866$, $p = 0.017$) but not for the shorter ride of 14 min ($F(1,144) = 2.035$, $p = 0.156$). As shown in Figure 6 (top left), for the longer ride, both women and men tend to show higher WTA values confronted with a shared ride with a member of the opposite gender. Being female and confronted with a male picture resulted in a higher WTA ($M = 72.70$, $SD = 19.36$) for the 25-min ride than when being confronted with a female picture ($M = 69.31$, $SD = 20.80$, $F(1,89) = 6.273$, $p = 0.014$) whereas the effect was not significant for male respondents ($F(1,53) = 1.264$, $p = 0.266$).

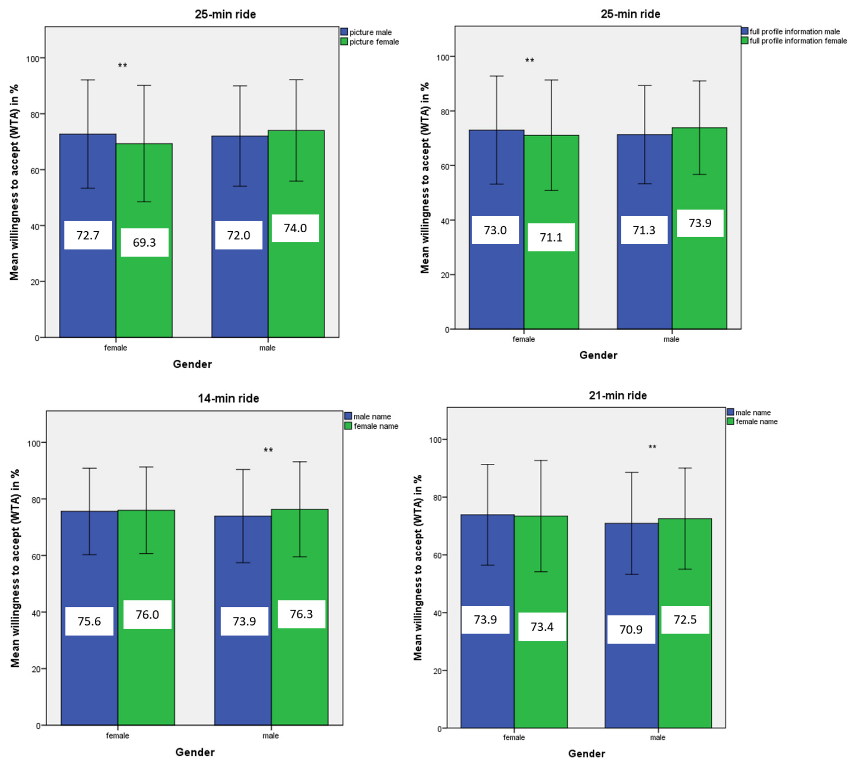

Figure 6. Mean Willingness to Accept (WTA) according to quality of information, gender information and respondent's gender. (**Top left**): 25-min ride under the condition Picture, (**Top right**): 25-min ride under the condition full profile information, (**Bottom left**): 14-min ride under the condition Name, (**Bottom right**): 25-min ride under the condition Name. Whiskers represent +/− 1 standard deviation, ** $p < 0.05$.

Under the condition *name*, a marginally significant interaction effect of gender information and own gender was shown for the shorter ride ($F(1,142) = 3.299$, $p = 0.071$) as well as the longer ride ($F(1,138) = 3.266$, $p = 0.073$). In more detail, it was shown that men, who were presented to a female name, indicated a higher WTA for the shorter ride ($M = 76.33$, $SD = 16.77$) than when viewing a male name ($M = 73.92$, $SD = 16.48$, $F(1,52) = 4.763$, $p = 0.034$, Figure 6, bottom left). The same inter-relation was shown for the longer ride ($F(1,52) = 4.510$, $p = 0.038$).

For the presentation of full profile information, a significant interaction with own gender was shown for the 25-min ride ($F(1,1424) = 5.306$, $p = 0.006$) but not for the shorter ride of 14 min ($F(1,150) = 0.848$, $p = 0.430$). As shown in Figure 6 (top right), for the longer ride, women showed higher WTA values when presented to a male full profile ($M = 72.98$, $SD = 19.80$) than to a female full profile ($M = 71.09$, $SD = 20.26$, $F(1,91) = 4.412$, $p = 0.038$).

3.3. Cumulative Distribution

The cumulative distribution of the WTA was used to assess the cost sensitivity of the respondents. The distribution function shows the share of respondents for a specific compensation demand (WTA). This information can be used to determine the WTA that is needed to attract a specific share of people, e.g., a critical mass of 90%. As shown in Figure 7, the distribution varied depending on travel distance (left) and automation scenario (right). As the left Figure 7 shows, a 14-min ride required a lower discount (50.00%) to attract the critical mass of 90% of respondents than a 25-min ride (62.22%).

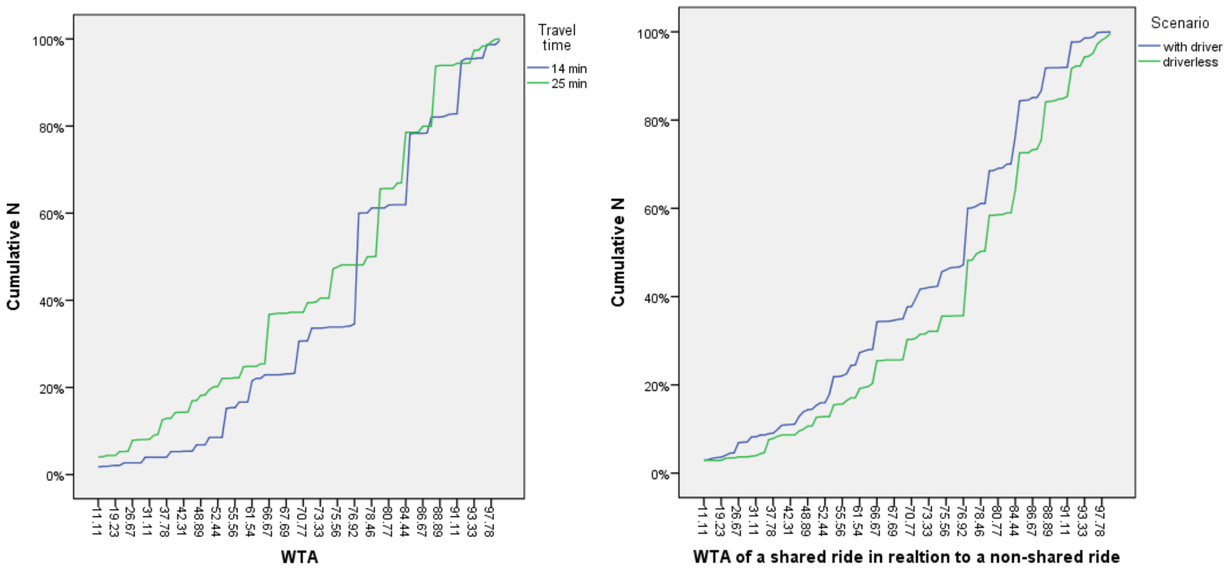

Figure 7. Cumulative distribution of the willingness to accept shared rides depending on the travel distance (**left**) and the degree of automation (**right**). The WTA of a shared rides is compared to WTA of the nonshared ride on the X-axis. Y-axis represents the distribution of the respondents.

Considering the effect of information on the cumulative distribution of respondents WTA, only slight tendencies were recognizable. As shown in Figure 8, the lowest discount needed to attract 90% of the respondents, as indicated by the highest maximum accepted costs was found under condition full female profile information. A critical mass of 90% of the respondents would share a ride if the price for the shared ride is 48.89% of the nonshared ride's price under this condition. In order to attract a critical mass of 90% of study participants, the maximum price accepted for a shared ride should be only 35.56% of the original price under condition male name.

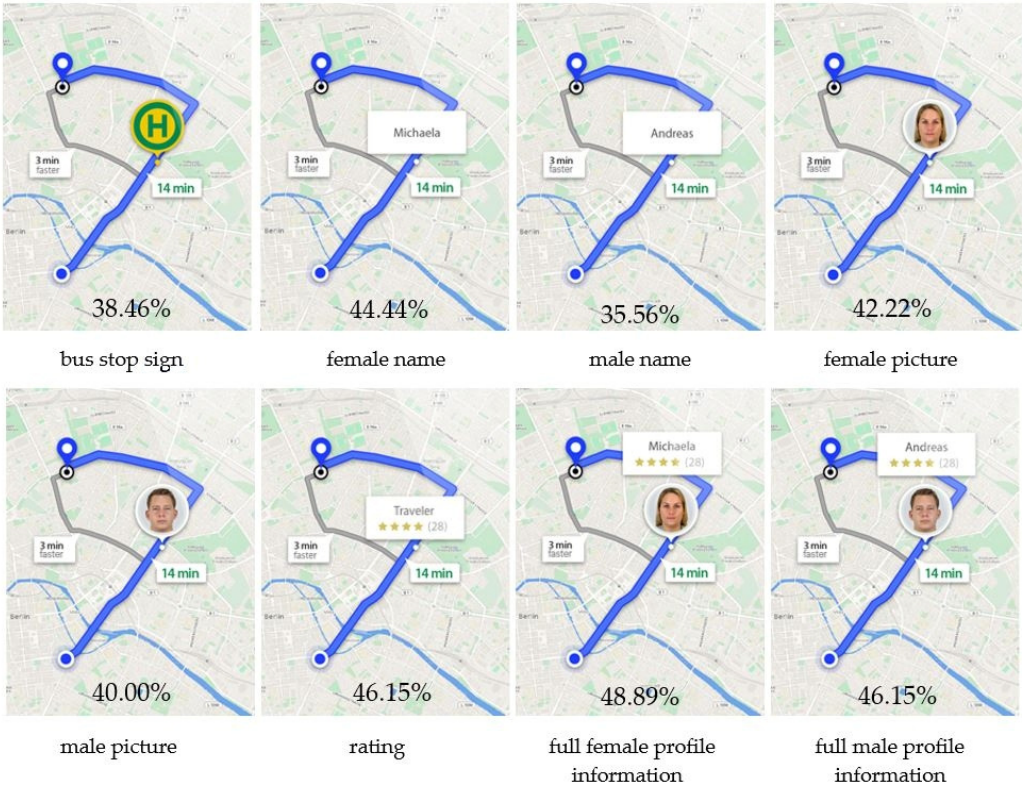

Figure 8. Maximum accepted price of a shared ride compared to a nonshared ride by a critical mass of 90% of participants depending on the information degree and the gender of the fellow passenger.

4. Discussion

4.1. Summary and Interpretation of Findings

It was shown that participants of the study revealed a high willingness to share rides in SAMODSs as indicated by a low overall refusal rate. The overall WTA for the shared rides as a measure of the compensation demands was nearly three quarters of the nonshared ride, indicating that regardless of the independent variables, the respondents required a reduction of approximately one quarter of the reference price.

Subsequently, the study findings are summarized by answering to the research questions concerned.

In terms of RQ1, the study found that the willingness to use SAMODSs was affected by the quality of information provided about fellow travelers. The likelihood of accepting a shared ride increases when more information is presented.

In more details, and to answer RQ2, the provision of detailed information about fellow travellers proved beneficial for reducing the compensation demands of travellers when sharing rides. Interestingly, the presentation of a name without further information on the fellow passenger decreased the willingness to share rides. The negative effect of the presentation of a name on the willingness to share rides was particularly relevant when male names were presented. The results are in line with the findings of Carol et al., (2019) who report a lower willingness to share a trip with male than female passengers for a ridesharing system [40]. They found strong indications for a discrimination of Turkish men in their study. Based on the result of the present study, the findings of [40] might be explained by the presentation of a name only. The provision of a rating proved relevant when looking at the cumulative distribution in terms of the maximum accepted costs of a shared ride (WTA) in relation to a nonshared ride. When a rating was presented, the lowest discount was needed to attract a critical mass of 90%. The beneficial effect of a rating system has been emphasized in several studies concerning ridesharing and ridehailing systems [39,57]. Concerning the information presented on the gender of the fellow passenger, the study found that male gender information was related to a higher refusal rate than female gender information. This was particularly relevant when only names were presented. A further statistical analysis revealed a correlation between the presented gender information under the condition *name and full profile information* and the respondents' own gender for men but not for women. Apparently, the above-mentioned negative effect of the presentation of a male name can be traced back to an interaction with the respondent's own gender in a way that men require higher compensation for rides with other male travelers when only name information were provided. Regarding RQ3, the effect of autonomous driving on the travelers' willingness to share rides could not be conclusively assessed based on the presented study results. Contrary to prior expectations, the study found no clear effect of the degree of vehicle automation on the willingness to share rides in SAMODSs as proposed by [10]. The study revealed a strong tendency towards the direction that participants that envisioned a ride in the driverless vehicle required less compensation for sharing rides compared to a conventional system with driver.

With regard to RQ4, the rejection rate of shared rides in SAMODSs was higher and correspondingly the required compensation demands were higher for longer rides as has been expected based on findings of prior studies [7,31]. However, the results are in contrast to the findings of Lavieri and Bhat (2018), who found the willingness to share trips in SAMODSs to be independent of travel time [10]. They propose that the willingness to share represents a fixed cost. However, the results of our analysis of the cumulative distribution of the WTA showed that the need for a price reduction increases with an increase in travel time.

4.2. Limitations and Further Research Needs

Several limitations have to be regarded for the interpretation of the study's findings. A first limitation of the study is related to the number of participants that requires a careful interpretation of the results. The authors thus recommend a validation of the findings based on different (e.g., other countries) and larger samples. A possible shortcoming emerges from the difficulty to create respondents' vision of the autonomous transport system even though they have not experienced the system before. One important limitation of the applied approach to use an online survey is therefore the challenge of ensuring a sufficient degree of immersion. Studies that use online surveys often report a limited external validity due to self-selection effects, among others [21,42,58,59]. As a means to face the challenge of immersion, the study used comprehensive explanation and a figural description of the transport systems. Furthermore, participants that did not remember the presented scenario correctly were excluded from further analysis. It may be an interesting starting point for future research to design experiments that mimic the travel experience in autonomous systems in a more realistic manner, like by using virtual reality [10] and naturalistic settings.

Based on the presented study, several new research questions are emerging. Because the study revealed a positive effect of the information provision concerning fellow passengers, further research is also needed to assess travelers' willingness to share personal data [60]. A comprehensive examination of privacy and safety concerns of existing pooled ride-hailing and ridesharing users may be a necessary step to design future autonomous mobility-on-demand-systems [10]. The guarantee of data security on the one hand, and the requirements for information provision about fellow passenger on the other hand, raises the question about registration requirements for users of SAMODSs. It might also be interesting to look at further incentive strategies to encourage sharing rides, like social nudges [61] or ecological framing [62].

5. Conclusions

A discrete choice experiment investigated the effect of providing information about the fellow passengers on the willingness to share trips in driverless autonomous mobility-on-demand systems. A discrete choice experiment assessed the potential of provided information on the participants' compensation demands for a shared ride. The analysis revealed a beneficial effect of detailed information about fellow travellers (picture, name and rating) for reducing the compensation demands of travellers. In contrast, the provision of a name only resulted in higher compensation demands. The study results could be used to design booking apps for shared mobility-on-demand systems that consider the users' needs concerning fellow passengers. Further research is needed to validate the results in further, more naturalistic settings and to examine travellers' willingness to share personal data.

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