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Assessment Methods for Comparing Shared Mobility and Conventional Transportation Modes in Urban Areas

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Abstract

Shared mobility is an innovative and sustainable approach to passenger transportation, which has only recently emerged. In urban areas car-sharing, bike-sharing and other special vehicles (e.g., scooters) are popular. For greater distances, ridesharing is considered as a great option beside own private car usage or public transportation. We elaborated an assessment to analyse mobility modes. The research consists of two main parts. First, a wide spectrum of key variables is identified. We classified the variables among the following indicators: flexibility, comfort, and dynamic characteristics. These indicators support mode choice decisions. The second part is the model of service level. In the model, we included parameters to represent the importance of certain attributes. The model can be used to support mode choice decisions. We applied the method to analyse a simple urban mobility palette and place shared mobility within it. We found that shared mobility modes can be placed between private car usage and public transportation according to the aggregated indicators.

Keywords

shared mobility, flexibility, comfort, travel chain, assessment method, analysis

1 Introduction

Shared mobility is defined as sharing of either a vehicle or a ride. Nowadays, several modes have emerged from this concept. In urban areas, car-sharing, bike-sharing, and ride-sourcing are the most popular modes. For interregional rides, ridesharing is widely used. Shared mobility is always demand responsive and requires an information system to either match drivers and passengers or drivers and vehicles.

Shared mobility modes and services compete with the use of one's own private car and public transport. In this research, we develop an assessment method to analyse modes and place shared mobility within the mobility palette.

Shared mobility mainly appears in the field of passenger transportation. Certain solutions are emerging in freight transportation as well. Based on Shaheen et al. (2020), we introduce seven key areas of shared mobility (Table 1).

In Table 1, in the left column, the type of sharing is given, while in the right column the key areas appear. Passengers can share a vehicle; the most typical mode in this segment is car-sharing and bike sharing in urban areas. Sharing of a delivery ride is possible as well; courier network services are efficient ways to distribute goods in urban areas.

Table 1 Key areas of shared mobility

Type of sharing	Key area
Sharing a vehicle	Car-sharing, scooter sharing, bike sharing
Sharing a passenger ride	Ridesharing, on-demand ride services, micro transit
Sharing a delivery ride	Courier network services

Shared mobility has several advantages and barriers (Katzev, 2003; Pyrialakou et al., 2016; Burghard and Dütschke, 2019). We identified three major advantages, as:

- *higher efficiency*, as the capacity utilisation is greatly improved (car- and ridesharing),
- *lower externalities*, as less vehicles are sufficient for carrying the same number of passengers, and
- *low technological requirements*, as shared mobility is mainly service development, which makes it an attractive development direction.

There are several barriers as well:

- *lower comfort and flexibility*, which also mainly pertain to car- and ridesharing,

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- *shared cars are affected by peak hour traffic as well*, meaning that shared mobility affects peak hour rush only if its' modal share is significant, and finally
- *owning a car is still a status symbol*, thus many citizens will stick to their cars, even if it means a significantly higher travel cost.

It is an efficient way to mitigate traffic congestion, by decreasing the number of unused seats per vehicle. This leads to reduced noise- and air pollution (Freudendal-Pedersen, 2020). Shared mobility modes have low technological requirements. Through using shared mobility modes, the passenger either does not need to share the vehicle or choose who they want to travel with.

On the other hand, several barriers may be observed. Owning and using private car has been a status symbol for many decades now. A private car is more flexible, it is comfortable, and it is always available. By using ridesharing, the passenger does not know the driver well. Car-sharing in urban areas is not faster than using a private car.

Analysis of shared mobility is a fast-growing research direction. Several papers are vehicle oriented and deal with vehicle-dependent situations. In general, the shared economy and its social, ecological, and economic impact have a rich literature background. Most of the literature is based on the concept of sustainability and handles shared mobility as a sustainable mobility solution. Sustainability and sustainable development have many layers and approaches (Glavič and Lukman, 2007). In mobility, the economic, social, and environmental aspects are most important.

We identified several, related research directions and areas, illustrated in Table 2. On the left, we list research directions, while on the right some of the most recently reviewed literature is given.

Table 2 Most recent research related to shared mobility analysis

Research direction	Reviewed literature
Society and people	Scavarda et al. (2020), Sopjani et al. (2020), Jiao et al. (2020),
Economics and policy	Efthymiou et al. (2013), Canitez (2020), Bardal et al. (2020),
Environment, sustainability	Severengiz et al. (2020), Dlugosch et al. (2020), Zavaglia (2016), Buzási and Csete (2016)
System and network design	Gecchelin and Webb (2019), McKenzie (2020), Bicocchi and Mamei (2014),
Optimisation	Kaddoura et al. (2020), Mourad et al. (2019).
Autonomous systems and control technologies	Lin et al. (2012), Dia and Javanshour (2017), Fagnant and Kockelman (2014)

Social questions are related to quality of life, everyday problems, spatial design, urban environment, or management frameworks. In this regard, authors highlight that those services should be available and accessible to everyone and support the equality of citizens. This is supported by e.g., dynamic fees, accessible infrastructure, and station design etc. Economics- and policy-related research deal with the shared economy, the impact of sharing for transport management, various simulation methods or institutional transferring. The research introduces shared mobility as a concept, rather than a set of modes. Several studies are environment related; impact, and sustainability are key terms (Buzási and Csete, 2015). Sustainability has three main areas: environmental, social, and economic (Nagy and Csiszár, 2020a). By implementing shared mobility solutions, progress can be achieved in all three areas. Shared mobility is able to reduce the negative externalities of passenger transport (e.g., air and noise pollution), as well as travel times, costs and congestion.

System design-related research handles the transportation network, station placement, free flow solutions and data analysis methods etc. Where shared mobility and the integration of shared-, public- and private services are concerned, station alignment is critical. There are various alignment methods; most recent studies tend to focus on methodology, which implicates geoinformatics based algorithms (e.g., particle swarm optimisation, agent-based models). Finally, optimisation deals with e.g., pricing problems, operational issues, traffic flow algorithms etc. Optimal pricing draws back to the previous point of fair pricing and aims to set a price or (dynamic) set of prices. Operational- and traffic flow optimisation aims to reduce congestion, and uses e.g., automated traffic control lights. Additionally, autonomous systems, vehicles and control technologies are taken into consideration as well. Control technologies are related to multiple reviewed areas (reducing externalities, flow optimisation, sustainability etc.) and influenced heavily by sharing vehicles. Autonomous shared mobility is a popular research direction. Sharing AVs is beneficial, as these vehicles will possibly be expensive, also with sharing efficiency always increase. Shared AV fleets mean new challenges in traffic control. As multiple authors uncovered, next to an increased efficiency, negative externalities may occur with AVs (e.g., increased total kilometres of travel, repositioning without passengers, new passenger groups changing from alternative or public transport etc.).

Comparison of shared and private modes were mainly done related to cars (private car, car-sharing, and ridesharing). Iacobucci et al. (2017) analysed policy aspects of shared transit. They found that the private sector applies shared modes more easily, while the public sector is usually constrained by regulatory issues. The status of shared modes is frequently not clear for city officials and transit agencies. They lack information regarding the state of transportation use and the share of individual modes. This tendency is exacerbated by the lack of available data, which leads to a situation where there is no platform for understanding why shared mobility is good, and who would be willing to use it.

Policy implications based on questionnaires are common when comparing shared and private/conventional modes (Becker et al., 2017; Sopjani et al., 2020; Huynh et al., 2020). In this sense, comparison is seen as *willingness to change from private or conventional modes to shared modes*. The results are mostly qualitative, and difficult to apply for objective comparison. These findings are highly related to social practice theories, and how major changes (e.g., change of commuting mode) work. For this, consumer behaviour analysis, and thus the TAM model is a favourable (based on Taylor and Todd, 1995).

Based on a survey, Mezei and Lazányi (2018) analysed smart development trends in public transport and similarly to us, assessed them according to 7 main parameters: safety, cleanliness, speed, precision, comfort, passenger friendship and sustainability. Puhe and Schippl (2014) carried out international research about user perceptions sustainable mobility, and compared Copenhagen, Budapest, and Karlsruhe. The results have showed that the development of shared mobility is not as important as public transport or biking from the passengers' perspective.

Comparison have been done, based on passenger trips as well (Tsai et al., 2008; Bongiorno et al., 2019; Nagy and Csiszár, 2020b; 2020c). Duration and length of trips determine, in which environment a service has the highest utility (e.g., ridesharing is mostly used for longer trips, outside urban areas). Spatial distribution has a similar function. Certain modes are compared to represent coverage, and characteristic trip types (e.g., inner-city – suburban). Finally, temporal manners are considered as well. Time of the day analysis enables us to know, for example which modes are preferred under peak hours or for commuting.

The reviewed literature is limited to comparing either private car to car- or ride-sharing or conventional public transport to shared modes. Another axis of limitation is the included aspects. Authors usually focus on a single aspect through the analyses.

Based on our state-of-the-art review, a complex and objective, private-public inclusive research has not yet been done.

The aim of this research is to rate and compare shared mobility services relative to (all of) the alternate modes in urban areas. The comparison has been done with three, aggregated indicators: flexibility, comfort, and dynamic characteristics. The analysis of shared mobility has not yet been done by the used aggregated indicators. Our hypothesis is, that by using the model, shared mobility services will be placed between own private and public transportation, regarding indicators. We illustrated the research process on Fig. 1.

2 Methodology

We introduce three aggregated indicators: flexibility (F), comfort (C) and dynamic characteristics (D). For these indicators, we introduced a set of key variables. The indicators are aggregated from those.

Furthermore, we set three modified indicators as well. Based them, we developed the model for service level (SL), as on Eq. (1):

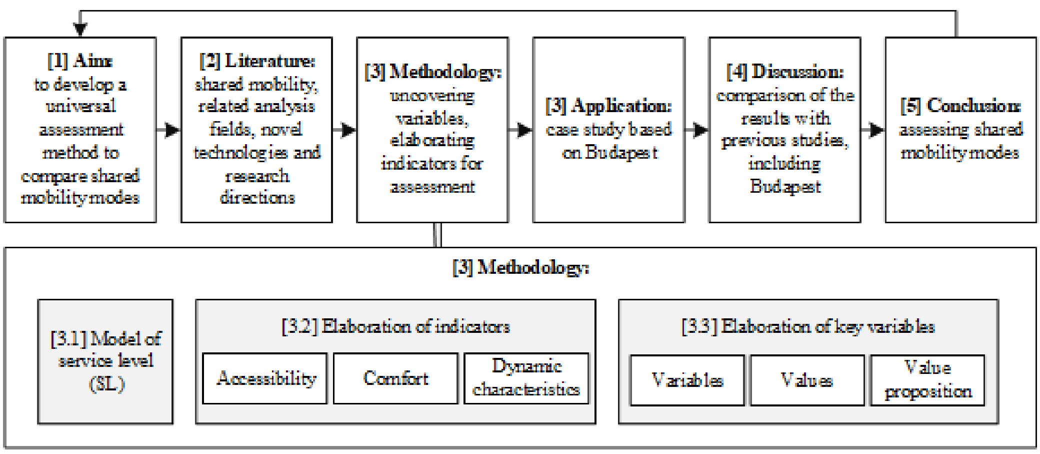

Fig. 1 The research process

$$SL = A_m + C_m + D_m, \quad (1)$$

where:

A_m stands for modified accessibility,
C_m is modified comfort and
D_m is modified dynamic characteristics.

The modified variables on the right side are calculated as a linear combination of certain variables and importance parameters. The importance parameters represent, how important a certain element is for the passenger. In this regard, we ask the passenger how important a certain variable for them.

These indicators are interpreted for three distance types: urban, interregional, and international. Urban distances refer to urban journeys. Interregional distances applied to interregional journeys e.g., regional railways, regional buses, travelling via car between two cities. Interregional journeys may be international but have a maximum distance of 150 kms. Lastly, international distances are regarding to international travels with distance greater than 150 kms.

The first indicator is accessibility, which is used both to access the vehicle and the stations. The key variables are presented on Table 3.

In Table 3., we summarised the variables on the left column, the values in the middle and the categories on the right. The values are between 0 and 1, where 0 is the least and 1 is the most accessible scenario.

Payment focuses on the mode of payment options, which the passenger can choose. In the best case scenario, the passenger can set up a plan (e.g., buy a season ticket or subscribe for a service) and can pay whichever way he or she prefers. Booking focuses on occasions when the passenger needs to book seats. Finally, the ticket variable refers to what type of ticket is available for the passenger. In the worst-case scenario only one-ride tickets are available and the passenger can only purchase them at the station. One-ride tickets, which can be purchased on the web are more flexible. In the best case scenario, the passenger can travel for a variable fee (e.g., the price is based on the distance travelled).

Table 3 The key variables of accessibility

Variable	Values	Categories
Boarding (f_1)	0 0.5 1	usage of other modes is needed, walking is needed, direct boarding available
Payment (f_2)	0 0.5 1	no choice available, payment choice available, but no plan, payment plan may be set up
Booking (f_3)	0 0.5 1	booking needed, multiple days before, booking 1–24 hours before the ride, booking is not needed
Ticket (f_4)	0 0.5 1	for one ride, bought near station, for one ride, bought on the internet, digital, variable fee, multiple rides
Schedule (f_5)	0 0.5 1	waiting time is relevant (few hours), moderate amount of waiting time, no waiting time

Interrelation may be observed between the variables, e.g., if the passenger e.g., sets up a plan or subscription. The ticket in this case is not required. For this, we presume, that the flexibility is great; the value of ticket and booking variables are 1.

The modified indicator of accessibility has been introduced, as the linear combination of the variables, as seen in Eq. (2):

$$A_m = \sum_{i=1}^{5} \lambda_i f_i, \quad (2)$$

where, λ_i is the importance parameter of element i and f_i is element i.

The second indicator, comfort and its key elements are summarised in Table 4.

The first variable, sharing is one of the most important issues of passenger transportation. Customisation issues how the passenger may customise the travelling space of the vehicle. Three options are defined: cannot customise anything (e.g., urban public transportation), can customise the seats or can customise the vehicle (e.g., own private car). Finally, activities related to the vehicle shows how much extra time besides travelling the passenger needs to spend to use the chosen mode.

The modified indicator of comfort has been prepared as the linear combination of the variables, as on Eq. (3):

$$C_m = \sum_{i=1}^{4} \lambda_i c_i, \quad (3)$$

where, λ_i is the passenger importance parameter of element $i(c_i)$.

Table 4 The key variables of comfort

Variable	Values	Categories
Sharing (c_1)	0 0.5 1	cannot choose who to travel with, can choose, but sharing is needed, sharing is not needed.
Seats (c_2)	0 0.5 1	comfortable for short term, comfortable for few hours, comfortable for several hours.
Customisation (c_3)	0 0.5 1	no customisation options, adjust seat, choose position, class, customise the vehicle
Activities (c_4)	0 0.5 1	all vehicle related activities, some issues, no need to handle anything.

Table 5 The key variables of dynamic characteristics

Variable	Values	Categories
Speed (d_1)	0 0.5 1	low, affects travel time greatly, speed does not affect travel time, high, affects travel time greatly.
Safety (d_2)	0 0.5 1	passenger is not safe feels safe, accidents are probable, passenger is safe.
Vigilance (d_3)	0 0.5 1	passenger is driving, take off at the right place, notified about everything.
Reliability (d_4)	0 0.5 1	system has stochastic anomalies, anomalies may be forecasted, system is reliable

The third indicator, dynamic characteristics, and its key elements are listed in Table 5.

Speed is relative to travel time and distance. For example, for greater distances, the speed of an airplane affects travel time greatly, which means $d_1 = 1$. On the other hand, for interregional distances, the speed difference of a fast railway (160 km/h) and private car (130 km/h) does not mean a big difference, both modes get $d_1 = 0.5$. Safety has two aspects: how safe does the passenger feel and how frequent accidents are. Based on this, the worst-case scenario is the passenger not feeling safe. Vigilance deals with if the passenger is the driver or just a passenger. The passenger status has two stances. The passenger must stay vigilant to get off from the vehicle at the right time and place (e.g., urban public transport) or if she or he is notified when to leave the vehicle (e.g., railway). Regarding autonomous vehicles, the methodology is applicable to compare different levels of automation as well as the automation of different vehicles. Lastly, reliability is focused on the transportation system (service and network). The main differentiating element is if the system has frequent anomalies or not. In this regard, anomalies mean infrastructural (e.g., congestion because of an accident), nature related (e.g., failure of overhead wire due to a storm) or service related (e.g., delays). Two scenarios are considered: the system has stochastic anomalies and has anomalies which may be forecasted. This forecasting is projective, based on past data. Best-case scenario the anomalies are very rare and easy to predict.

The modified indicator of dynamic group, as the linear combination of the key variables are presented on Eq. (4):

$$D_m = \sum_{i=1}^{4} \lambda_i d_i , \tag{4}$$

where, D stands for the dynamic group, λ_i is the passenger importance parameter of variable $i(d_i)$.

Besides the developed model of delivered service level, by aggregating the key variables the level of flexibility, comfort and dynamic characteristics can be calculated as well. To achieve this, first we need to define the discrete values of the variables for the chosen modes. To separate the modes and the characteristic values, we calculate deviation for every indicator and mode, as on Eq. (5):

$$\sigma\left(j;I\right) = \sqrt{\frac{\sum x_i - \overline{x}}{\left(n-1\right)}} , \tag{5}$$

where:

$\sigma(j; I)$ is the deviation of mode j in indicator I,

x_i is the value of variable i of mode j in indicator I,

$\overline{x}$ stands for the average of mode j in indicator I,

n is the number of variables in indicator I.

By the usage of deviation, it is possible to represent the variability of the values on a figure and illustrate the modes.

This should happen in multiple distance types, as different modes are used for different distances. This way mobility modes in the same distance type can be compared. We apply the method for urban distances.

3 Application

The considered urban area has the following characteristics:

- using private car is not favourable, congestions are frequent, parking is difficult;
- advanced public transportation system (APTS) is available;
- free flow car-sharing is available;
- ridesharing is popular, citizens may use it;
- bike sharing system is available, has several passes/ticket types, subscription to the service is easy.

These characteristics are based on Budapest. There are two exceptions, which make the urban relation a bit more theoretical: APTS, bike-sharing and bike infrastructure. APTSs using wide information and communication technologies for multiple purposes (Adeleke et al., 2013). The bike-sharing system is well designed, has several ticket types and plans available. The bicycle infrastructure in the city has good network coverage.

We analysed own private car (PC), public transportation (PT), car-sharing (CS), ridesharing (RS) and bike sharing (BS) modes. In Table 6., we summarised the aggregated indicator of accessibility.

For urban distances, private car is the most accessible. The passenger may use it door-to-door, booking, ticket or adaptation for schedule is not needed. The owner, however,

Table 6 Accessibility in urban distances

Variable	Values				
	PC	PT	CS	RS	BS
Boarding (f_1)	1	0.5	0.5	0.5	0.5
Payment (f_2)	0.5	1	0.5	0.5	1
Booking (f_3)	1	1	0.5	0.5	1
Ticket (f_4)	1	0.5	1	1	0.5
Schedule (f_5)	1	0.5	1	0.5	1
Accessibility (A)	4.5	3.5	3.5	3	4

must deal with several payment issues (e.g., taxes, maintenance etc.). The least accessible mode is ridesharing. Public transport, car-sharing and bike-sharing are in between.

In Table 7., we defined the variables and the aggregated indicator of comfort.

In urban areas, the most comfortable mode is bike-sharing. It has one advantage against private car: the user does not need to handle any vehicle related activities. Private car, car-sharing and ridesharing are second. By using private or shared car, the passenger does not need to share the vehicle. By using ridesharing, the passenger/driver can choose who to travel with, though sharing is needed. Private car is the most customisable. By the usage of car- and ridesharing, the passenger's customisation options are reduced. We differentiated these modes by vehicle related activities as well. With private car, the owner must deal with all issues. Car-sharing only requires some issues and ride-sharing the passenger does not need to handle anything. The least comfortable mode is public transportation.

We summarised the last indicator, dynamic characteristics in Table 8.

Regarding speed, bike-sharing may give a great advantage to the user in peak hours. This requires a well-designed biking infrastructure with good network coverage. On the other hand, safety is a weak point for bike-sharing. Regarding vigilance, three modes require the user to drive (private- and shared car, bike-sharing). Bike-sharing is a bit more resilient, than the other four modes. It is easy to set up alternative routes, to dodge traffic anomalies.

We calculated the deviation for each mode in each indicator. Based on the aggregated indicators and the deviation, we summarised the results and illustrated them on Fig. 2.

In Fig. 2, grey stands for public, blue for private, and green for shared transportation. The size of the circles represents the deviation of the certain modes. On the vertical axis, the values of the aggregated indicators are presented. On the horizontal axis, the three indicator categories can be found.

Table 7 Comfort in urban distances

Variable	Values				
	PC	PT	CS	RS	BS
Sharing (c_1)	1	0	1	0.5	1
Seats (c_2)	0.5	0	0.5	0.5	0.5
Customization (c_3)	1	0	0.5	0.5	1
Activities (c_4)	0	1	0.5	1	0.5
Comfort (C)	2.5	1	2.5	2.5	3

Table 8 Dynamic characteristics in urban distances

Variable	Values				
	PC	PT	CS	RS	BS
Speed (d_1)	0	0.5	0	0	1
Safety (d_2)	0.5	0.5	0.5	0.5	0.5
Vigilance (d_3)	0	0.5	0	1	0
Resilience (d_4)	0	0	0	0	0.5
Dynamic characteristics (D)	0.5	1.5	1	1.5	2

The results show that shared mobility modes are not found in-between private and public transportation. Instead, in most cases, they keep the same variable values. In the deviation, there are no significant differences between the modes.

4 Discussion

The model of service level may be used in a route planning application to support mode choice decisions. Based on the model, an algorithm can be implemented and used in a smart application. In that application, the passengers would define the value of the importance parameter. The value set can be based on a Likert scale of five. The application would give a route and a travel chain for the passenger.

Current literature partially includes the variables introduced by us. *Willingness to pay and willingness to use* (Akbari et al., 2020) analyses usually introduce aspects, found in our accessibility indicator (f_1 – f_5), as well as further variables, such as speed, customisation, or activities. Usage comparisons usually focus on a single mean and its' sharing. *Dynamism of transportation modes* have also been compared in literature. Network resilience and modal resilience have great importance while designing a transportation system or establishing a new service (Nagy and Csiszár, 2021). *Safety analysis* and accidents are also often researched fields (Chaudhry et al., 2018; Haworth et al., 2021). Safety analyses usually are limited to a single mean of transportation or comparing two services of the same vehicle (e.g., private car to car-sharing or private e-scooters to shared ones).

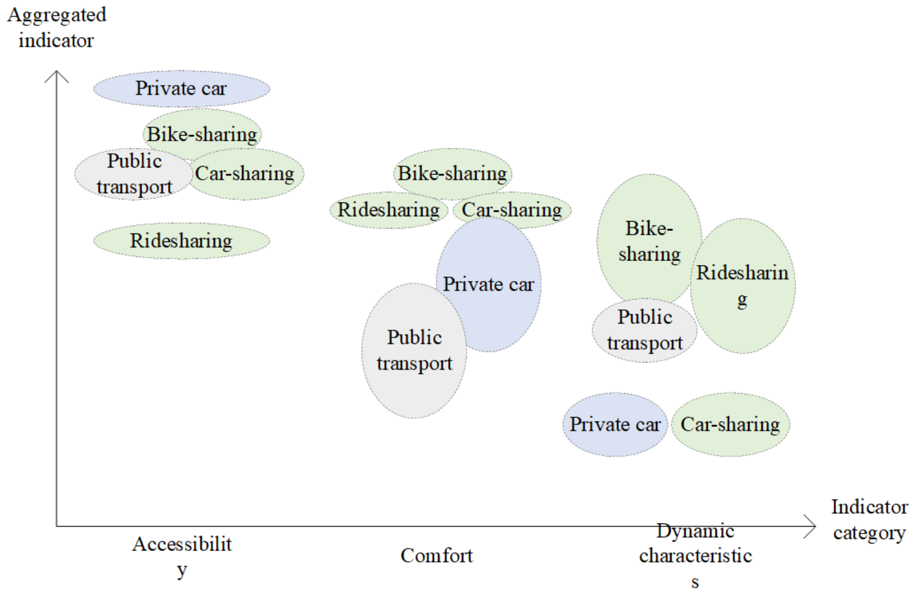

Fig. 2 The analysed mobility modes in urban distances

In practical application, key variable scale detail can be increased, as in a programming environment this is easily implemented. Passengers' opinions are practically asked in a smart device application, where the Likert-scale of 5 can also be replaced, however, usage of a scale of five is widely accepted and we would not recommend more complex scales, as passengers can be overwhelmed by them.

There are a few aspects, that we did not include. Environmental externalities, such as air- and noise pollution or energy intensity can be included for a more in-depth comparison (Nazelle et al., 2012; Nijland and Meerkerk, 2017; Bigazzi, 2019; Nemoto et al., 2021). Shared mobility is usually seen as a sustainable alternative to private modes in these regards as well. Environmental impact of shared mobility is also connected to social issues and quality of life. Next to shared mobility, autonomous- and shared autonomous vehicles appear as new transport modes.

This assessment method is a new concept for analysing shared mobility as part of the mobility mix or travel chain. The developed assessment method is applicable for several stakeholders of passenger transportation. First, service providers can use it to determine their price and service features. Secondly, passengers can use it to ease their choice of mode and help them to insert shared services in their everyday trips. Lastly, cities can use it, since by using the method, shared mobility modes may be integrated into the travel chain.

5 Conclusion

We developed an assessment method for analysing mobility modes. The assessment method contains key variables, aggregated and modified indicators and the model of service level. The novelty of this assessment method is its objectivity, and the ability it provides to compare all the available modes systematically.

The results did not support our hypothesis: *shared mobility is not necessarily between private and public transport modes*. We found that private car always has inordinate values. It is either the best or one of the worst alternatives. Overall, the private car is at the low end. We uncovered that the psychological value of owning and using a private car is more important for the passengers than its practical advantages.

Our future research first would focus on each indicator and the more detailed (continuous) value setting of the variables. Secondly, based on the more detailed value set, by using the delivered service level, we will aim to develop an algorithm that supports mode choice decisions. This algorithm would be used in e.g., a smart phone app. Finally, the next step can be envisaged as the inclusion of autonomous and shared autonomous vehicles as new services, which can be expected to appear in the future.

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