User expectations towards mobility services based on autonomous vehicle

David Foldes
Department of Transport Technology and Economic
Budapest University of Technology and Economics
Budapest, Hungary
foldes.david@mail.bme.hu

Csaba Csiszar
Department of Transport Technology and Economic
Budapest University of Technology and Economics
Budapest, Hungary
csiszar.csaba@mail.bme.hu

Azamat Zarkeshev
Department of Transport Technology and Economic
Budapest University of Technology and Economics
Budapest, Hungary
zarkeshev.azamat@mail.bme.hu

***Abstract*— The current transportation system, services, and traveler's habit are altering as the Autonomous Vehicles (AVs) emerge. The individual car travels are more and more replaced by shared, demand-driven mobility services based on small capacity AVs. The exploration of user expectations is needed to plan, organize and operate these novel mobility services properly. The questions of our research were: what kind of service characteristics are expected by the travelers and how the expectations are influenced by the socio-demographic characteristics. Accordingly, the mobility services and the planning functions were identified. The traveler expectations were measured by a complex questionnaire survey. Several correlations between the socio-demographic characteristics or current mobility habits and the expectations towards the future services were revealed. The results can be applied for planning the transport process and the related information management.**

Keywords—autonomous vehicle, mobility service, user expectations, stated preference, questionnaire survey

I. INTRODUCTION

The transportation system is altering due to the technological development (e.g. automation) and the spread of efficiency enhancement approaches (e.g. sharing economy). Expectedly, shared, mainly on-demand mobility services based on Autonomous Vehicles (AVs) emerge which are accessible via a mobile application. It is called STA - Shared Transportation based on AVs [1].

AVs are still in the test phase; the main scope of autonomous vehicle technology researches are among others the control of vehicles, the communication system, the interaction of other vehicles, pedestrians or bikers, as well as the testing and validation of new components [2]. Therefore, the planning of mobility services based on AVs is also in the early phase. The acceptance and easy adoption of AVs can be significantly enhanced by a highly personalized mobility service considering the user expectations.

The research aimed to reveal the user expectations towards mobility services based on AVs. The research questions were:

- what kind of service characteristics are expected?
- how are the expectations influenced by the socio-demographic characteristics and the current mobility habits?
- how should the expectations be considered during the mobility service planning?

The user expectations were measured by a questionnaire survey. The correlations revealed from the responses can be applied during the mobility service planning. In this paper, we applied our previously determined planning framework for such a mobility service [1].

The rest of the paper is structured as follows: in Section II, a brief review of the related works is provided. In Section III, the mobility service types and the planning functions are summarized. The survey structure and the elaboration method of the questionnaire survey are presented in Section IV. In Section V, the most relevant results are summarized and discussed; namely, the correlations between the questions. Finally, the conclusion is drawn, and further research directions are summarized.

II. LITERATURE REVIEW

The aim of the literature review was, on the one hand, to summarize the scientific works dealing with user expectations towards mobility services based on AVs; and on the other hand, to reveal the relevant questions which can be incorporated into our survey. Several studies address the user acceptance which is assessed by either questionnaire survey (e.g. [3], [4], [5], [6], [7]), or interview (e.g. [8], [9]).

The individual acceptance (ready to use) and the societal acceptance (accepted by the whole society) of an innovation, such as AV, can be distinguished [10]. According to the 'diffusion of innovations theory', the users are influenced to accept and adopt an innovation by both external (e.g. media) and internal (e.g. personal experience) circumstances. As an innovation achieves the so-called critical mass, where the adoption rate increases due to an imitative attitude, it is likely to gain universal adoption [11]. Different acceptance levels are distinguished (e.g. willingness to use, actual use) and in addition, the acceptance can alter also in time (before, during and after use) [10]. The acceptability can be measured before the use (as an expectation), whereas the acceptance itself is to be measured after the use (as a revealed preference) [12]. Measuring the acceptance of a mobility service based on AVs is rather difficult as bare experience is available. Consequently, the expectations can be measured according to the stated preferences. Nevertheless, the user cannot imagine the AVs adequately, therefore only the assumptions can be revealed.

Acceptability is predominantly influenced by the perceived usefulness, expected effort, ease of use and the social influence [13]. The following factors may increase the number of AV users: technology promotion, raised willingness to pay for shared services, and unusually rapid reduction in technology costs [14]. Furthermore, the concerns about software hacking/misuse, legal, and safety issues should also be dissolved [3]. The socio-demographic characteristics, especially the age, influence the perception and attitude towards AV [7]. The public attitudes in urban areas are rather positive [6]. One-quarter of the respondents interested in sharing AVs. It has been found [8] that low waiting time and smartphone ordering are required for a highly automated service. Furthermore, other service attributes such as travel cost, travel time and waiting time may be also critical determinants of the use of this mobility service [5].

The trust towards AVs is related positively to the behavioral intention to use self-driving vehicles [15], [16]. The user trust can be improved by hands-on experience [12]. In some test cases, the acceptance has already been measured. The users' reactions towards a small capacity service were rather positive in an EU trial project [17]. It has been found [9] that technology of the current automated shuttle does not meet the expectations, but respondents still perceive these shuttles as a viable option as feeders to public transport systems if flexible, comfortable, fast and reliable transportation is provided.

We conclude from the literature review that socio-demographic characteristics (e.g. age) significantly influence expectations and acceptability. Furthermore, expectations towards general mobility service attributes should be considered during the planning of mobility service based on AVs.

III. Mobility Service

The boundaries between the individual transportation and the conventional public transportation are blurring by the so-called transitional transportation modes, such as ride-sharing, car-sharing, taxi, and ride-sourcing. These transitional modes provide demand-driven or demand-responsive, mainly shared mobility services. A demand-driven service is operated only if any travel purpose is registered; neither the route nor the timetable is predetermined (e.g. taxi). The aim is to enhance the capacity utilization with the shared use of a vehicle either in time or during a ride (seat sharing). Whereas a demand-responsive service is characterized by a flexible timetable and capacity according to the current demand; the route may be predefined (e.g. DRT).

The vehicles of the urban motorized transportation become highly automated or autonomous. The current transitional modes, moreover a significant share of individual car use can be replaced by the STA. However, the high, one directional demand can be efficiently served only by the public transportation in the future too. In addition, the role of walking and cycling remain significant.

A. STA Service Types

There are several visions for the application of small capacity AVs (e.g. [5], [13], [18]). They can be applied as a feeder or a last-mile service with or without seat capacity sharing. The STA services are provided either by car or small capacity bus (pod). The vehicle is operated by any type of companies (or private person), but the services are managed by the integrated mobility management center. A flexible tariff system according to the current demand and capacity is to be applied. Pre-ordering of the service is mandatory mostly via mobile application. The service types (Figure 1) and characteristics are as follows [1]:

- S_1 **taxi**: provides individual door-to-door service between any departure and arrival points without capacity sharing.
- S_2 **shared taxi**: provides door-to-door service between any departure and arrival points with capacity sharing.
- S_3 **feeder pod**: provides feeder service from any departure points in a zone to the stop of a high capacity line; transfers are guaranteed by semi-fixed timetable. The operation is symmetric in the opposite direction.
- S_4 **fixed route pod**: provides mostly feeder service on fix route. The departure and arrival points are fix stops. It is operated according to a timetable, but additional departures may be inserted according to demand.

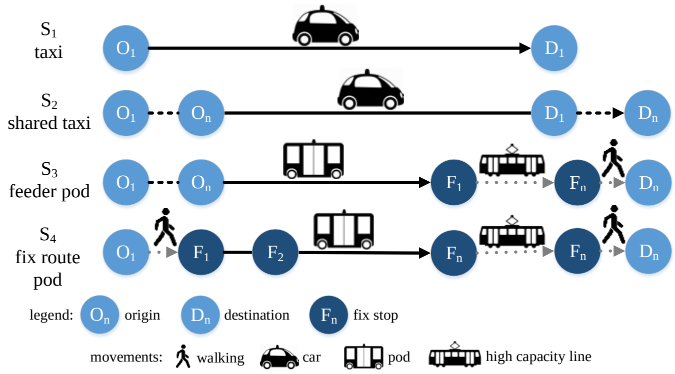

Figure 1. STA service types (source: [1])

B. *Planning functions*

The service is planned by the integrated mobility management center and the operators. However, the cooperation with other additional organizations (e.g. infrastructure operators, municipalities) are necessary. The service planning functions of the STA are grouped as follows:

Preliminary planning:

- basic service planning:

  P_A service type
  P_B fix stop/route
  P_C capacity
  P_D charging infrastructure
  P_E fee collection

- information service planning:

  P_F mobile application services
  P_G on-board services

Operative planning:

P_H run
P_I maintenance

Even though the planning functions are similar to those of mobility service based on conventional vehicles, new methods are needed due to the technological advances. Most of the functions can be fully or partially automatized. Though the driver's work regulations can be neglected, new solutions are needed both in the operation (e.g. charging) and in the passenger handling (e.g. information provision) due to the reduction of human staff. The most significant operational challenges are the real-time demand-capacity coordination, personalization of the services, and charging the vehicles. Functions regarding additional operational process (charging infrastructure, maintenance) do not require data from the users directly. However, the user expectations can be an important information source for planning the other functions.

IV. METHOD – QUESTIONNAIRE SURVEY

We performed a questionnaire survey to reveal the user expectations towards the mobility services based on AVs. The structure of the questionnaire is presented in Fig. 2. The questions are indicated by boxes. The questions were assigned to the following groups:

I. socio-demographic characteristics,

II. current mobility habits and

III. expectations toward the STA.

The first index of a question cites the question group. The color represents the question type.

The planning functions were considered during the compilation of the questions in group III. Input data of the functions can be gained from the responses. As the mobility services based on AVs are still not available in the studied region (Hungary), the questionnaire included a detailed description of the AVs and the service types.

The user-related questions are classified according to the current mobility habits, socio-demographic characteristics and the use of STA types. The mobility service related questions may refer to the information service or the basic service (fee collection or movements). Sub-questions are used for different motivations and service types. The (sub)questions can be answered according to the predefined options. An option reflects the preference and being represented by a value.

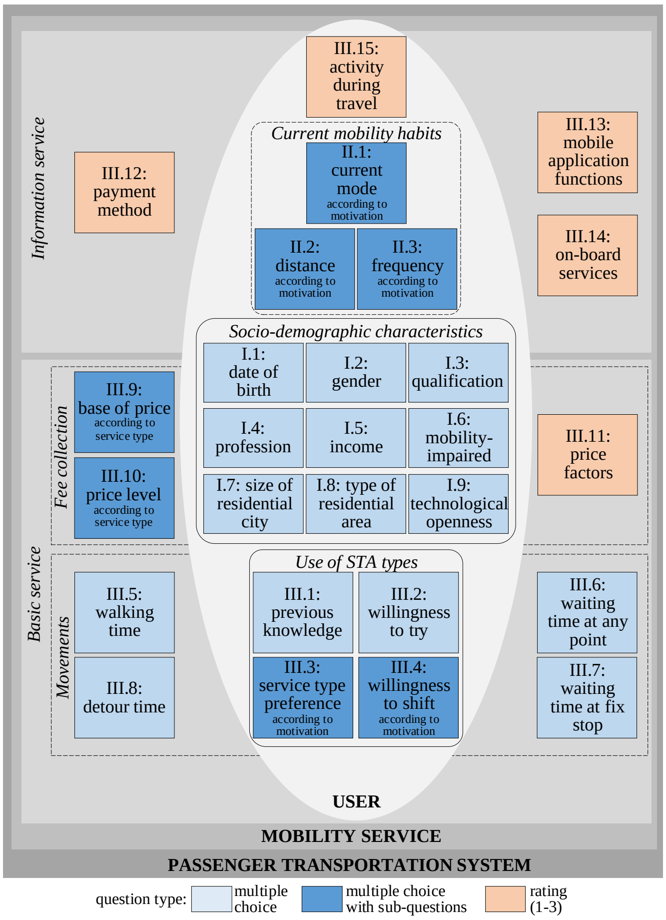

Figure 2. Structure of the questionnaire (source: based on [1])

The introduced question types are the following:

Multiple choices: an option is selected from a list [19]:

- without sub-question (light blue), for instance: III.6: How long would you wait for the STA at an optional point? Options: a) <5 min, b) 5-10 min, c) >10 min,
- with sub-questions (dark blue): indicated by a matrix where the sub-questions are presented in rows, options are presented in columns. For instance: III.3 Which service type do you prefer in the case of a certain motivation? The question is presented in Table I.

Rating: indicated by a matrix where the sub-questions are presented in rows, the options are presented in columns. The respondents evaluate the sub-questions using the same set of values (1-3 value - so-called Likert-scale [20]). For instance: III.14. How important are the following on-board services for you? The question is presented in Table II.

TABLE I. MULTIPLE CHOICE QUESTION WITH SUB-QUESTION - EXAMPLE

service type / **motivation**			**options**			
			S_1 taxi	***S_2 shared taxi***	***S_3 feeder pod***	***S_4 fix route pod***
sub-question	***a***	***working***				
	b	***shopping***				
	c	***leisure activity***				

TABLE II. RATING QUESTION - EXAMPLE

on board services			**options**		
			1: not important	***2: important***	***3: very important***
sub-question	***a***	***WiFi***			
	b	***installed smart devices***			
	..	***…***			
	f	***staff attendance***			

The questionnaire was created in ‘Google Forms’ web-based application. The resulted database contains a main table about the responses and several code-tables which detail the options (e.g. description). The raw data were processed by queries ($Q_{m,n}$ where *m* refers to the number of a question). The aim was to determine parameters which can be used for the service planning. The questions of group III were considered for this purpose. For instance, the following queries were formed:

$Q_{III.6,1}$ what is the average waiting time at any point?

$Q_{III.3,1}$ how many respondents select S_1 taxi service type to work?

A further aim was to reveal the correlation between the socio-demographic characteristics or current mobility habits and the expectations. Accordingly, the responses from question group I or II are used in a query condition. For instance, only the disabled respondents can be considered (according to I.6. question).

A service parameter is described by the options. It is determined as follows:

- If values are not assigned to the options in a multiple-choice question, the percentage of an option selection is calculated. The service parameter is determined according to the percentages.
- If values are assigned to the options in a multiple-choice question (III.-5-8, 11), the values according to each response are averaged. In the case of intervals (e.g. III.6), the mean values are considered. The service parameter is determined according to this averaged value.
- In the case of rating questions, the values according to each response are averaged. The service parameter is determined according to this averaged value.

The correlation between two questions is strong if an option of a question explicitly determines an option of another question. In other words, several respondents chose the same option ‘pair’ from two questions.

V. RESULTS AND DISCUSSION

We performed the survey via the internet in February 2018 in Hungary. 510 responses have been received. Statistical or random sampling could not have been executed. The questionnaire was spread via web forums of professional and non-governmental organization as well as among university students. Although the sample is not representative, relevant consequences can be drawn as the number of the respondents is relatively high.

Although the AVs are considered as a new technology, nearly 2/3 of the respondents has heard and being interested in them (question III.1). The willingness to try an AV is promising (question III.2). Almost 50% of the respondents would try it without any doubt, 38% of them only when they are widely used, 10% when a trusted friend has tried it with satisfaction, and only 3% would never try it.

The correlation between the willingness to try and the technological openness is illustrated in Figure 3. The charts represent the proportion of the respondents who choose a certain option about the willingness to try. Two categories of the respondents according to the technological openness have been illustrated. For instance, ‘try AV without any doubt’ option is selected by 61% of the fully opened respondents, whereas the same option is selected only by 24% of the partially opened respondents. We found it as similar to [21]; namely, the **technological openness significantly influences the willingness to try an AV**.

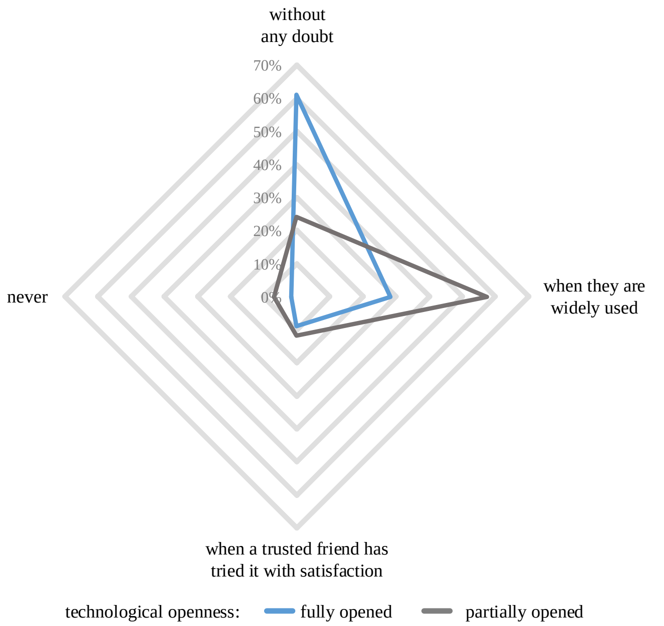

Figure 3. Willingness to try according to the technological openness

Hereinafter, the revealed correlations are presented in accordance with some relevant planning functions.

P_A – service type selection: the service type preference (question III.3) is determined according to the travel motivation. Figure 4 represents the proportion of respondents. We found that **the travel motivation and the service type**

preference are strongly correlated. The fix types (S_3, S_4) are preferred for less flexible motivation (e.g. work/school), whereas the flexible types (S_1, S_2) are more likely preferred for the ad-hoc motivation (e.g. leisure activity). This closely resembles the current mobility habits. The 2/3 of the respondents travel to work with public transportation recently; the characteristics of S_3 and S_4 types are rather close to the characteristics of the current public transportation.

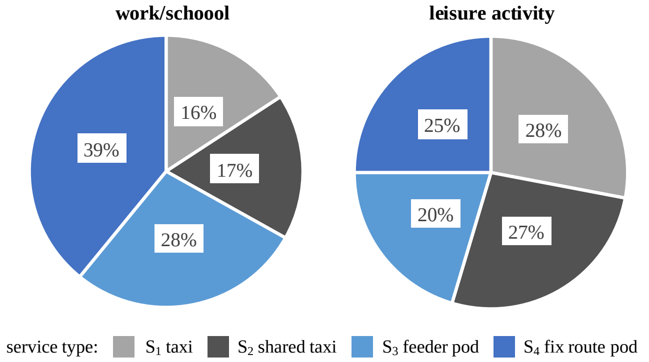

Figure 4. Service type preference according to motivation

Furthermore, like [5] and [13], we also found that the **service type preference is strongly influenced by the current mode use** (Figure 5). Individual car use is represented by grey squares, public transportation use is represented by blue squares. Individual car users prefer the most flexible S_1 type and refuse the fix S_4 type. The tendency is just the opposite in the case of public transportation users.

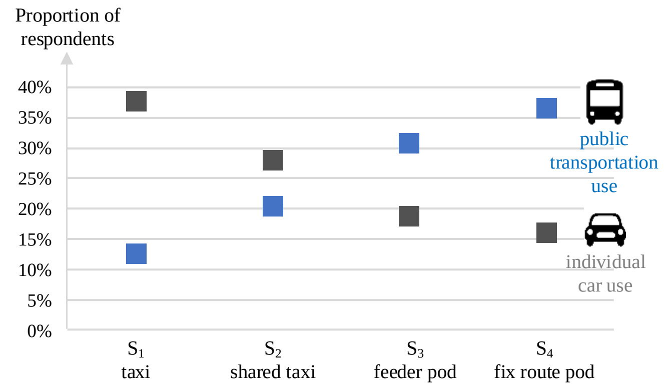

Figure 5. Service type preference according to the current mode use

The willingness to shift (question III.4) in the case of working motivated travel is examined according to the current mode use. Figure 6 presents the prevalence of the shifting. It is the highest among the individual car users; almost 60% of them would shift on several occasions. Whereas bikers' and pedestrians' willingness to shift is the lowest. We found that **individual car use can be significantly reduced by shared and on-demand services based on AVs**. The same conclusion was drawn by [22] and [23]; however, according to [24], the respondents' reactions were less indifferent and much more refusing. For example, 54% of them rejected an on-demand service.

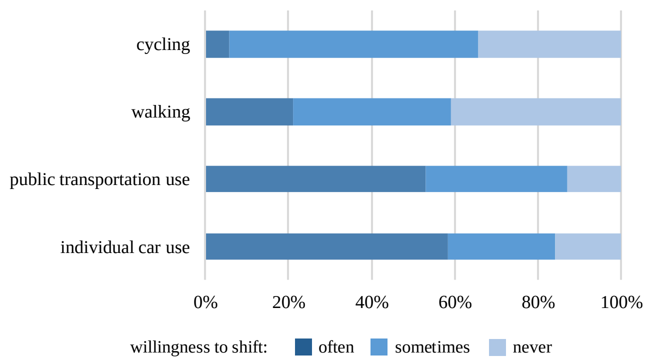

Figure 6. Willingness to shift according to current mode use

P_B – *fix stop/route assignment*: it is influenced by among others the willingness to walking; namely, the accepted walking time (question III.5). We found that **the age, the size of the residential city and the current mode use influence the willingness to walk**. The next groups are willing to walk more: youngers, respondents living in a suburb and current public transportation users. Furthermore, we found that **the willingness to walk for a service based on an AV is less than the willingness for a service based on a conventional vehicle.** The acceptable average walking distance to STA is 280 meter, whereas this distance to conventional public transportation bus is 400 meters on the average [25].

P_C – *capacity planning*: the determination of timetable and vehicle number is influenced by among others the willingness to wait; namely, the accepted waiting time at any point or fix stop (question III.6-7). The average accepted waiting time at any optional departure points which are served by S_1-S_3 is 6.4 minutes from the ordering to the arrival of the AV. Moreover, the accepted waiting time at fix stops are less, it is 5.4 minutes on the average. The short service time can be guaranteed by demand prediction and the spatial allocation of the vehicles.

Furthermore, we found that **willingness to wait and current mode use are strongly correlated** (Figure 7). The current car users' willingness to wait is lower than the average one; whereas that of the public transportation users is higher.

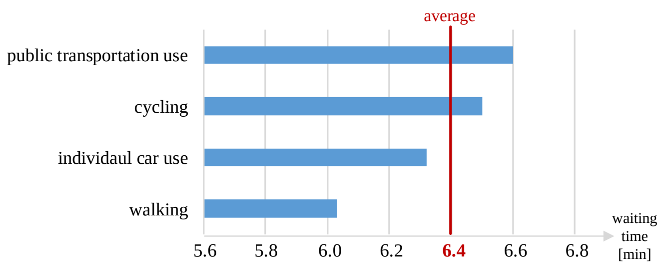

Figure 7. Willingness to wait according to the current mode use

P_E – *fee collection*: the expectations towards the characteristics of the tariff system play an important role during its planning. The following expectations are measured: base of price, price level, price factors (questions III.9-11). The price factors decrease or increase the price considering any discount or penalty.

The base of price can be the number of boarding, travel duration, travel distance or the combination of distance and duration. Boarding-based tariff is independent of both distance and time. The preferences of the different base of prices according to the service types are presented in Figure 8. We found that **boarding-based tariff is popular in the case of inflexible service types** (S_3 and S_4). The possible reason for this statement is that boarding-based tariff is applied typically in the public transportation in Hungary and the service types S_3 and S_4 are rather similar to the public transportation. Although the flexible service types (S_1 and S_2) are similar to current taxi services, not the combination of distance- and duration-based tariff applied by current taxi services is preferred for them. We found that **the distance-based tariff is the most popular in the case of flexible service types**.

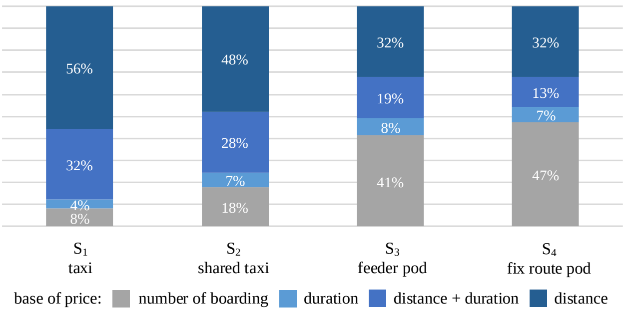

Figure 8. Base of price preference according to service type

The preferences of price levels according to the service types are presented in Figure 9. Instead of specific prices, approximate descriptive options could have been selected. We found that **the more flexible the service is, the higher the acceptable price level is.**

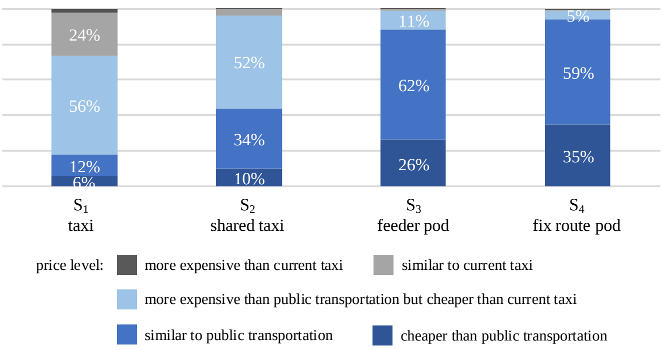

Figure 9. Price level preference according to the service type

Furthermore, the correlation between the socio-demographic characteristics and the acceptable price level is also examined. Contrary to the results of [4], **youngers are willing to pay a higher price than the elders.** E.g. In the case of S_1 type, 29% of the members of Y generation, but only 14% of the members of X generation are willing to pay the same price as for a current taxi service.

The following statements are made about the price factors. The travelers are willing to pay a higher price (app. 19% higher)

- in peak hours or
- if the fellow passengers can be selected (e.g. based on profile picture).

They expect a price reduction

- if the service is ordered 30 minutes before (16 % reduction is expected) and
- in the case of regular (almost daily) use (24 % reduction is expected).

The fee collection should be planned according to the preferred payment method (question III.12). The average importance of the payment methods is presented in Figure 10 using a scale of 1 to 3 where 1 means ‘not important’ and 3 means ’very important’. **The most popular methods are the payment by contactless card or via a mobile application**. The low preference for automatic payment (e.g. based on the user position) can be explained by the novelty of this technology. In addition, the impacts of socio-demographic characteristics on the importance of each payment method are also examined. **The youngers**, especially the members of the Z generation who use often the mobile applications, **consider the mobile payment as more important** (2.55).

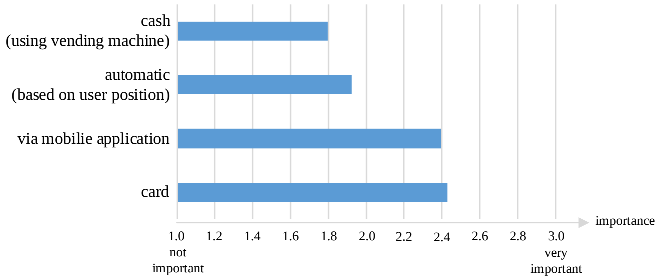

Figure 10. Importance of payment methods

P_F – mobile application services: The average importance of mobile application functions (question III.13) is summarized in Figure 11 in a scale of 1 to 3 where 1 means ‘not important’ and 3 means ‘very important’. We found that **functions regarding the use of mobility service** (d-e) **are highly important; whereas, functions regarding the service quality** (a-c) **are less important.**

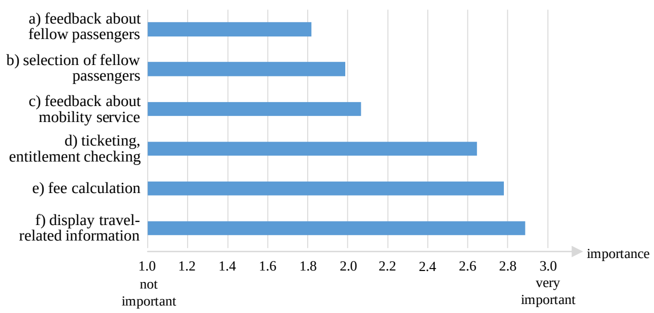

Figure 11. Importance of mobile application functions

P_G – *on-board services:* The average importance of each on-board service (question III.14) is summarized in Figure 12 in a scale of 1 to 3 where 1 means ‘not important’ and 3 means ‘very important’. We found that **services providing travel-related information along with the services supporting the use of individual smart devices** (free WiFi, chargers for individual smart device) **are the most important**. Contrary to the results of [6] and [26], the presence of human staff is not considered as an important issue (importance ~1.7). Moreover, the disabled and visually impaired respondents consider it slightly more important than the average (importance ~2). 6% of the respondents plead to be disabled or visually impaired. The mobility services based on AVs are especially beneficial for them or others without the ability to drive [27].

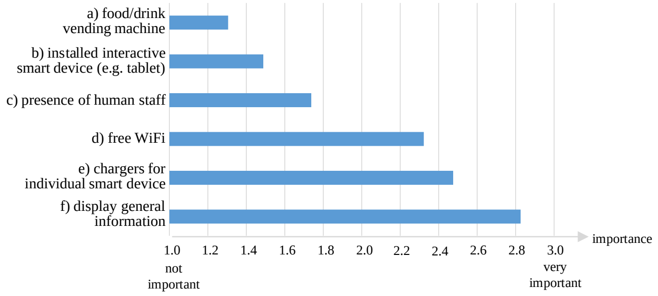

Figure 12. Importance of on-board services

The passenger comfort services should be planned according to the preferred activities instead of driving (question III.15). The stated average frequency of the activities is presented in Figure 13 in a scale of 1 to 3 where 1 means ‘never’, 3 means ‘often’. The current bikers’ and car users’ average frequencies are highlighted. Their responses are more relevant as they can perform fewer activities currently because of the necessary driving tasks. As long listening music/radio and talking is possible during driving, the other activities (c-g) can be performed only as a passenger. We found, like [4], that **activities which are possible during driving remain popular** (listening music/radio, talking). Furthermore, we found, like [3], that **some activities, which are limited or impossible to do during driving, become popular in the future** (looking around, surfing on internet/chatting, working/learning). Contrary to the result of [24], car drivers would work/learn more frequently. In addition, bikers would look around or have a rest/sleep very often.

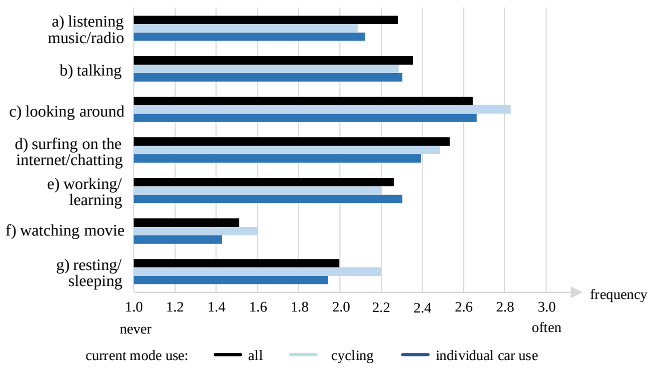

Figure 13. Frequency of alternative tasks

P_H – *run planning:* the planning of the useful runs is influenced among others by the detour time for a fellow passenger (question III.8). The respondents tolerate app. 6 minutes detour time per an urban, feeder travel in general.

VI. Conclusion

The shared, mostly on-demand mobility services based on small capacity AVs are still in the planning and test phase. The user expectations must be taken into account during planning. The main contributions of the paper are the following:

- a questionnaire survey to measure the user expectations (as stated preferences) towards the (shared) mobility services based on AVs,
- analysis of the expectations according to the mobility service planning functions.

We found:

- Technological openness significantly influences the willingness to try an AV.
- The preferred service type is influenced by the travel motivation and the current mode use.
- Individual car use can be significantly reduced because the willingness to shift is high.
- Current mode use influences the willingness to walk and wait.
- The willingness to walk for a service based on small capacity AV is less than that in the case of a conventional bus.
- The more flexible the service is, the higher the acceptable price level is.
- The mobile application functions that help the use of the mobility service are the most important (ticketing, entitlement checking; fee calculation; display travel-related information).
- Services providing travel-related information, along with the services supporting the use of individual smart devices (free WiFi, chargers) are the most important on-board services.
- Activities which are limited or impossible to do during driving become more popular in the future (looking around, surfing on the internet/chatting, working).

The novelty of the AVs and thus the lack of knowledge about them were the most challenging issue during the preparation of the questionnaire. The questions had to be compiled so that they could have been answered only with little knowledge. Nevertheless, relevant consequences could have been drawn. In the future, further correlations are to be revealed; the common impacts of socio-demographic and current mobility habits to the expectations are going to be examined. The research potential in this area is quite significant; our future research focuses on the elaboration of the listed planning functions revealing the transformation of input data to output data.

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