QUALITY ASSESSMENT METHOD FOR MOBILITY-AS-A-SERVICE BASED ON AUTONOMOUS VEHICLES

Yinying He[1], Csaba Csiszár[1]
[1] Budapest University of Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Department of Transport Technology and Economics, Budapest, Hungary

Abstract: The Mobility-as-a-Service (MaaS) concept is proposed to readdress the integration of transportation modes regarding information management, especially customized multimodal journey planning, booking, ticketing and payment. When conventional road vehicles are replaced by autonomous road vehicles (AVs) in the MaaS, the service processes alter significantly. Service quality reflects features of the service in an aggregated, objective way. Service quality assessment is essential for service planning and operation. The research question is how to evaluate the expected quality of this new service (MaaS based on AVs). We have identified the quality criteria, taken both user expectations and operator purposes into consideration. The Analytic Hierarchy Process method (AHP) has been applied to determine the weights. The service quality evaluation index system is established based on the criteria and their corresponding weights, a ten-point scoring method is proposed to score the expected service quality. One example is presented for demonstration purpose. The elaborated new assessment method is applicable to score the expected quality of this new service, to compare the expectations/attitudes of various groups (transportation experts, potential users, service providers, MaaS operators, etc.), in order to support decision making when planning and introducing such a new service.

Keywords: Mobility-as-a-Service, autonomous vehicles, service quality assessment, Analytic Hierarchy Process (AHP) method.

1. Introduction

The Mobility-as-a-Service based on Autonomous Vehicles (MaaS based on AVs) is a data-driven, user-centric, car-usership oriented, integrated public mobility service, which is proposed on hypothesis that high level integration of transportation modes could be realized. The MaaS operator is a new role, it acts as an intermediary between users and transport service providers. The mobility service is booked or purchased directly from the MaaS operator rather than the single service providers. The so called transitional mobility services (e.g. car-sharing, ride-sharing, ride-sourcing) are to be replaced by autonomous pod service in the MaaS based on AVs, to provide the either door-to-door or first/last mile mobility solution. The pod term covers mini, small or medium capacity vehicles. The conventional public transportation service (e.g. bus, tram, metro) remains for large volume passenger transit purpose; however, it becomes more automated or autonomous (Földes and Csiszár, 2016). We consider only one MaaS operator and focus on user-vehicle assignment of passenger transportation in urban area. Other relevant issues (e.g. goods delivery, vehicle charging, parking, reallocation) of the MaaS based on AVs belong to our further research work.

Definition of the proposed new mobility service types, elaboration of the system structure and the operational model, as well as the calculation principle of dynamic pricing, were the most relevant contributions of our previous work (He and Csiszár, 2018). Accordingly, questions of how to design, model and operate such a new mobility service have been studied. However, the service quality issues are to be still explored. Service quality reflects features of the service. Quality assessment is essential for service planning and operation. Therefore, in this paper, our main research question is how to evaluate the expected quality towards this new service. We unfold this main question into three sub-questions as following:

1. which quality assessment criteria are to be introduced?
2. how are the weights of criteria to be determined?
3. what are the application opportunities of this assessment method?

The personal flexible transit (PFT) is a mini pod service with limited capacity; one vehicle serves only one user with private space. Small group rapid transit (SGRT) is used as a shared service (with unknown people) or car-rental purpose (one user books a vehicle and share it with familiar people, e.g. friends, families); the small capacity vehicle serves 2-6 users. The special demand responsive transportation (SDRT) is defined for mobility-impaired users. The small capacity vehicles (2-6 users) are equipped with extra devices (e.g. ramp, voice-based guiding system). The group rapid transit (GRT) is a feeder service to conventional public transportation with medium capacity vehicles (7-12 users), Both, the timetable and the route are determined in advance. All these services are shared types and reservation is required to guarantee a seat. In order to provide a high-quality mobility service, users are not allowed to stand on these vehicles. Furthermore, these on-demand services may replace the conventional public transportation service in the night in case of the lower mobility demand and energy saving purpose.

The remainder of the paper is structured as follows. State of the art is summarized in Section 2. In Section 3, the service quality assessment method is elaborated; namely, establishing, scaling and weighting of quality criteria are presented, respectively. The weights of the criteria, one example to demonstrate the applicability of the assessment method, as well as the further application opportunity are as results and discussed in Section 4. The paper is completed by Section 5 as a conclusion, including further research directions.

[1] Corresponding author: yuzhange@outlook.com

2. State of the Art

From the users' perspective, service quality may involve two aspects, expectation towards and perception of the service (Mugion *et al.*, 2018). Users satisfaction is also derived from the perceived quality. From the service provider's perspective, the relevant aspects are the targeted (planned) and provided quality. In our approach, the quality of the MaaS based on AVs refers to the 'bridge' between the providers' targeted and the users' expected service quality. In order to simplify, it is still called the expected service quality.

Deb and Ahmed (2018) find that both perceptions and expectations of the passengers are important to estimate the service quality. Safety, comfort, accessibility and timely performance are the most relevant factors in this analysis. In another research, waiting time, cleanliness and comfort are found as three main variables of the service quality (dell'Olio *et al.*, 2011). A research review about quality attributes of public transport concludes that service reliability, frequency as well as these attributes connected to individual perceptions, motivations and contexts are relevant ones (Redman *et al.*, 2013). In order to address the importance of service quality attributes, two customer satisfaction survey methods (questionnaires and face-to-face surveys) using the same case study of Madrid (Spain) are compared. The novelty of this study is that a comparison between two quality survey methods is provided. Furthermore, a method to estimate attribute importance directly from a stated preference survey is also elaborated (Guirao *et al.*, 2016). Service quality has a direct effect on the intention to use the public transport service and sustainable means of transportation such as car-sharing and ride-sharing more. Consequently, the use of one's own car is to be less (Mugion *et al.*, 2018).

According to the hypothesis that higher level of mobility integration is more appealing to users, the existing MaaS schemes are evaluated and compared by using several criteria (ticket integration, payment integration, ICT integration and mobility package integration) and the mobility integration index has been introduced (Kamargianni *et al.*, 2016). A compensated multicriteria method is developed to analyze and assess the quality of European carsharing systems. This method takes both the service properties and user expectations into consideration (Csonka and Csiszár, 2016). The pairwise weighting method of AHP is applied to derive priorities for different criteria for shifting urban commuters to the public transport system. Reliability, comfort, safety and cost as 'parent criteria' are identified based on literature review and expert opinion in this study (Jain *et al.*, 2014). Quality criteria of a cargo transportation service are introduced as the price of transportation, safety, reliability, accessibility of the service and duration of delivery. The weights of the criteria are determined based on the mean value of four assessments of experts. The safety criterion is assessed as the most important one regarding of competitiveness of a cargo service (Matijošius *et al.*, 2016). A multicriteria model based on user perceptions to assess urban public transport is developed and implemented in Florianópolis, Brazil. In this study, the pairwise comparison method is applied to scale evaluation descriptors and an evaluation equation is presented to calculate the aggregated value of the service quality (Barbosa *et al.*, 2017).

We conclude from the literature review that transportation service quality assessment requires rather complicated research and 'soft' (subjective) criteria are more focused in recent years. Several studies assess the service quality by applying the existing quality criteria (e.g. in the case of a bus service). Furthermore, the pairwise comparison method of AHP is also applied in several papers but with different weighting approach. Most of the quality assessment methods refer to the conventional public transportation; accordingly, quality related researches regarding the new mobility services based on AVs fill a significant 'research gap'. Our service quality assessment method presented in this paper is a new approach. We have identified the quality criteria for this new service (MaaS based on AVs), the pairwise comparison of 1-9 scaling and weighting method of AHP (Saaty, 1977) are applied to scale and weight the criteria. Then the service quality evaluation index system is established based on the criteria and their corresponding weights, a ten-point scoring method is proposed to score the expected service quality, here the quality criteria are to be graded (scored) as evaluation index. The comparison/analysis of the scored aggregated quality value is the applicable opportunity of the method.

3. Methodology

In the developed quality assessment method, both the operator purposes and user expectations have been taken into consideration. The steps of the method are summarized in Fig. 1.

Step 1: the quality criteria are determined according to the relevant research studies (e.g. mobility service operation), forecasted service properties and user expectations. This step is the real novelty of the assessment method, because this mobility service has specific new characteristics/attributes (e.g. integrated smart phone application, travel fellow selection, PFT service, opportunities of wifi and charging (phones) in vehicles). These new characteristics are highlighted and combined with the existing/old ones.

Step 2, 3, 4: the AHP method is applied to scale, check (and calibrate) and weight the criteria. The 1-9 scaling of pairwise comparison method has been applied. The weights of each level criteria regarding their corresponding upper level criteria are calculated first as local weights, then the aggregated weights of criteria regarding the service quality Q are calculated as global weights.

Step 5: the calculation method (equation) of the aggregated quality value (Q) is introduced. The assessment method is completed with the entire established quality criteria as well as their corresponding global weights.

Application step: the quality criteria are as evaluation index to be scored. The importance of each criterion (index) is ten points. The final (aggregated) value of service quality Q is calculated.

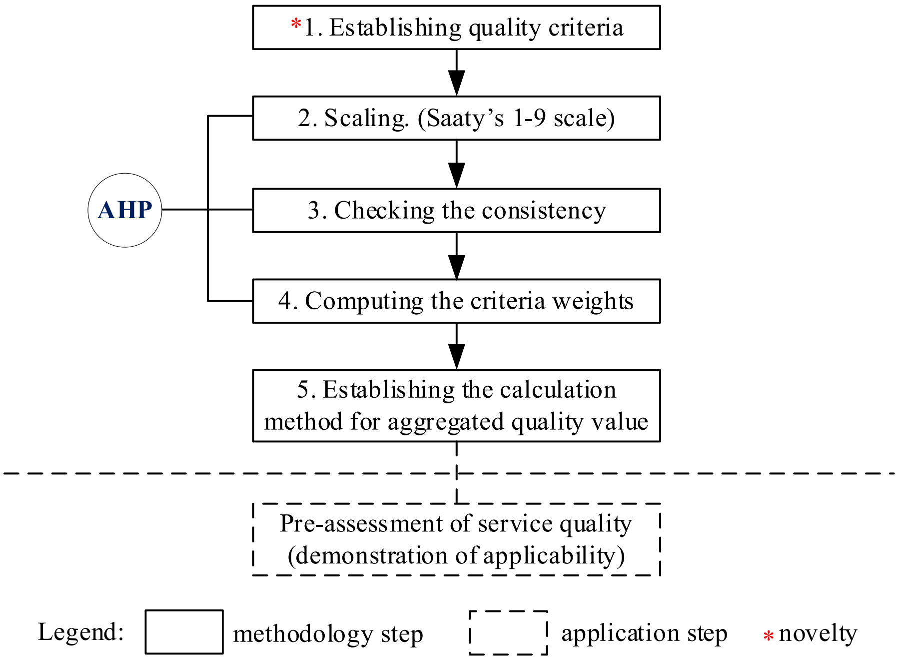

Fig. 1.
Steps of the Method

3.1. Establishing Quality Criteria

The service quality criteria have been identified according to various literature review (e.g. user expectations towards MaaS, acceptance of AVs and shared AVs, integration level of mobility services), MaaS projects (e.g. interface of smartphone application, questions of surveys, impact assessments), operational aspects (e.g. frequency, dynamic pricing, tariff structure) and forecasted service characteristics of our previous work. The hierarchical structure of quality criteria is presented in Fig. 2.

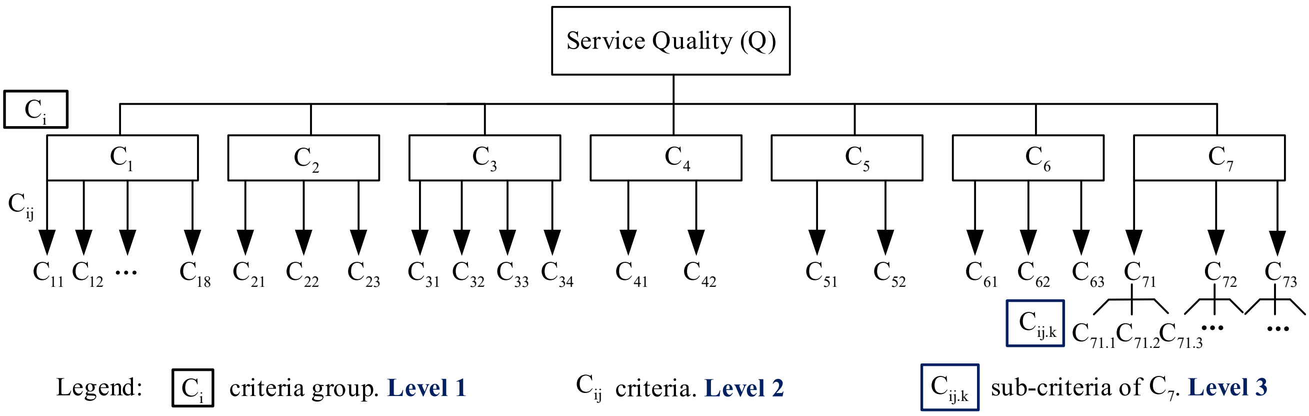

Fig. 2.
The Hierarchical Structure of Quality Criteria

Three levels of criteria are proposed. The first level criteria groups (C_i, C_1 to C_7) mainly refer to public transportation: C_2 Availability, C_3 Accessibility, C_4 Information, C_5 Time, C_6 User care and C_7 Comfort (EN.13816:2002). The C_1 Speciality group is introduced to identify the most relevant characteristics of this new service. The second level criteria (C_{ij}) are put in the focus of the assessment method, the corresponding local and global weights of each criterion is to be calculated (in this paper, weights of C_{ij} regarding C_i and $C_{ij.k}$ regarding C_{ij} are local weights, weights of C_i regarding Q and C_{ij} regarding Q are global weights). The third level sub-criteria ($C_{ij.k}$) are introduced only with the C_7 criteria group. On the one hand, 'comfort' is a quite subjective criteria group, the single criteria are not enough to describe it in detail. On the other hand, users are willing to pay more for the higher comfort service, and comfort can be improved with less effort compared to other criteria related aspects.
The elaborated service quality criteria are presented in Table 1. The other public transportation related criteria groups are eliminated or merged, e.g. security, environmental impact (EN.13816:2002). As the security and safety issues of AVs are still not matured enough (laws, regulations, responsibility, etc.), the pairwise comparison of their importance with importance of other criteria is not possible. The emergency management is considered with criterion C_{61}. Namely,

during establishment of the quality criteria Table 1, we assume that the basic requirements of security and safety are met. Environmental impact C_{16} as a criterion belong to C_1 Speciality.

Table 1
Service Quality Criteria

Criteria			**Details**	
C_i	C_{ij}	**name**	**description/ $C_{ij.k}$**	
C_1 **Speciality**	C_{11}	**integrated smart phone application**	integration of function of planning, booking, ticketing and payment in one application	
	C_{12}	**travel fellow selection**	user can choose (sympathetic) travel fellow	
	C_{13}	seat position selection	for SGRT and SDRT service	
	C_{14}	application reminders	calendar/transfer point reminder, etc.	
	C_{15}	personalization	recommendation of preferred route, trip, combination of transportation modes, etc.	
	C_{16}	environmental impact	battery electricity vehicles, lower pollution	
	C_{17}	**PFT service**	individual mini pod transit	
	C_{18}	dynamic pricing	variable price, similar approach as in the case of Uber	
C_2 **Availability**	C_{21}	operating hours	24 hour, non-stop	
	C_{22}	frequency/regularity	timetable (GRT) or on-demand service	
	C_{23}	average distance to reach the service	GRT (distance $\leq$ 250m)	
C_3 **Accessibility**	C_{31}	**ticketing and payment**	electronic ticket, one ticket for an entire journey, etc.	
	C_{32}	ticket validation	QR code scanning or NFC technology	
	C_{33}	booking	instant booking or pre-booking	
	C_{34}	tariff structure	pay per use, monthly package, etc.	
C_4 **Information**	C_{41}	real-time information	vehicle tracking, current network condition, boarding/alighting points identification, emergency information, etc.	
	C_{42}	feedback	suggestion or complaint	
C_5 **Time**	C_{51}	estimated time	trip time, transfer time, etc.	
	C_{52}	punctuality	delay $\leq$ 5minute	
C_6 **User care**	C_{61}	emergency services	E-call, etc.	
	C_{62}	user support service by personnel	24 hours	
	C_{63}	**special care (for impaired)**	wheelchair space, ramp, human assistance, etc.	
C_7 **Comfort**	C_{71}	supplementary service	$C_{71.1}$	**charging (phones) in vehicles**
			$C_{71.2}$	**wifi in vehicles**
			$C_{71.3}$	**entertainment devices and services**
	C_{72}	vehicle condition	$C_{72.1}$	cleanness of vehicle (both outside vehicle body and inside cleanness, e.g. window, seat.)
			$C_{72.2}$	odour (smell) in vehicle
			$C_{72.3}$	ergonomic design (e.g. seat comfort)
	C_{73}	waiting station (GRT)	$C_{73.1}$	cleanness
			$C_{73.2}$	seating opportunity
			$C_{73.3}$	weather protection

Such an envisaged, integrated, multimodal mobility service is to be realized via a single interface on smartphones, therefore the C_{11} integrated smartphone application is chosen as an important criterion to assess the functionalities of journey planning, booking, ticketing and payment. In the case of SGRT and SDRT services, users may have the opportunity to select the travel fellow (C_{12}) and seat position (C_{13}). Accordingly, travel fellow selection relate feeling of security and comfort. The function of application reminder C_{14} (e.g. calendar reminder, vehicle arrival reminder) is more and more embedded in the existing MaaS smartphone applications; however, this tendency may be clearer in the applications of the MaaS based on AVs. Function of smart recommendations according to users' preferences and behavior is already embedded into other information services, e.g. e-shopping (Amazon), entertainment (Youtube, music player), e-news. Such function (C_{15} personalization) is to be considered also for mobility services, e.g. recommendation of travel time and shortest route according to users' preferred routes/combination of transportation modes. PFT service C_{17} is listed individually, because the size of vehicle may be an advantage of parking space. The similar approach is as in the case of Uber service, price is charged according to real-time demand. C_{18} dynamic pricing is applied to better conciliate the demand and capacity (e.g. lower price is charged by pre-booking, because the time is enough to coordinate tasks and optimize the vehicle run).

3.2 AHP: Scaling and Weighting

The multicriteria analysis method is widely used to support decision making (San Cristobal, 2012). The AHP method is one method of multiple criteria decision analysis (Bhushan and Rai, 2004). In our work, the elaborated hierarchical structure of the criteria is the base of AHP method, then the Saaty's 1-9 scale method (Saaty, 1977) is applied to scale pairwise comparisons. The numerical values towards pairwise comparisons are presented in Table 2. The 'element(s)' word in Table 2 refer to the criteria (criterion) in this paper.

Table 2
Saaty's 1-9 Scale

Numerical values	Option (verbal scale)	Explanation
1	**equal** importance of two elements	two elements contribute equally
3	**marginally strong** importance of one element over another	experience and judgement favor one element over another
5	**strong** importance of one element over another	one element is strongly favored
7	**very strong** importance of one element over other	one element is very strongly dominant
9	**extremely strong** importance of one element over another	one element is favored by at least an order of magnitude
2, 4, 6, 8	**intermediate values** to reflect **fuzzy inputs**	used to compromise between two judgments
reciprocals	reflecting dominance of second alternative compared with the first	relative comparison

Source: (Saaty, 1977), (Bhushan and Rai, 2004)

Considering the hierarchy levels, the criteria groups (C_i), criteria (C_{ij}) and sub-criteria ($C_{ij.k}$) are all scaled by pairwise comparisons within each level. The scaling results are square matrices (the comparison matrices). The comparison matrix of second level criteria M_i are as examples and presented as following:

$$M_i = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1j} \\ x_{21} & 1 & \cdots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{j1} & x_{j2} & \cdots & 1 \end{bmatrix}$$

Where i is the index number of criteria group C_i, M_i is the comparison matrix of criteria C_{ij} regarding C_i. j is the index number of criteria. For example, M_1 is the comparison matrix of C_{11} to C_{18} within criteria group C_1. x_{12} is the scale value of the importance of C_{11} and C_{12}. All values on the primary diagonal are 1. Because of pairwise comparison and according to Table 2 (reciprocals), $/x_{j1}=1/x_{1j}/$. From matrix M_1 to M_7, together with M_{71}, M_{72}, M_{73}, as well as the matrix M^* contained C_1 to C_7, totally 11 matrices are established at first. We use the comparison matrix M_3 of criteria C_{31} to C_{34} to demonstrate in detail.

$$M_3 = \begin{bmatrix} 1 & 1 & 2 & 2 \\ 1 & 1 & 3 & 1 \\ 1/2 & 1/3 & 1 & 1/2 \\ 1/2 & 1 & 2 & 1 \end{bmatrix}$$

x is used to represent the scaling value. For example, $/x_{21} = 1/$ is the scale value of criterion C_{32} compared with C_{31}, namely, the ticket purchase method (electronic ticket) has equal importance of the ticket validation method (QR code scanning or NFC technology). $/x_{23} = 3/$ is the scale of criterion C_{32} compared with C_{33}, namely, the favor of criterion ticket validation method is marginally stronger than the booking method (instant booking or pre-booking), and $/x_{32} = 1/3/$ represent the importance of C_{33} is marginally weaker than the C_{32} (Table 2, reciprocals). There is no strict rule towards how to scale the value of 'importance', according to the fuzzy approach (Table 2) of Saaty's method, value depends on the individual 'favor' (or according to experience) which criterion. In the presented example M_3, the ticket validation method is more important by assuming that users prefer the quicker ticket checking process in general. Several users may prefer the booking method and opposite scaling value may occur. The AHP is a kind of open method, but the relatively subjective scaling process are controlled by the further consistency checking step. All the scaled matrices are checked by Saaty's method, the consistency of those matrices is ensured at a mathematical theory level. The other criteria are pairwise compared in the similar way. The scaling of the criteria is according to the general experience, literature review, comparison of existing MaaS models, etc. In our work, 1-6 scale is applied for all the matrices (the introduced criteria are with similar importance, without wide gap towards importance between two criteria), except M_4 matrix, where 1-8 scale is introduced (compared C_{42} feedback, the importance of C_{41} real-time information is quite stronger, the scale 8 is assigned).
The next step is to check the consistency of the comparison matrices by Saaty's Consistency Index (CI) and Consistency Ratio (CR). The checking requirement is $/CR < 0.1/$ (Saaty, 1977). If $/CR > 0.1/$, then the examined matrix has to be adjusted or redone (re-examined). CI is calculated by equation (1).

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{1}$$

$\lambda_{\max}$ is the maximum and principal eigenvalue of matrix M_i, and n is the rank of matrix M_i, M_i is square matrix with $n \times n$. W is the eigenvector of matrix M_i. $\lambda_{\max}$ and W are to be calculated by equation (2).

$$\left(M_i - \lambda_{\max} \cdot I\right) \cdot W = 0 \tag{2}$$

Replace CI with the equation (1), CR is to be calculated by equation (3)

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{RI \cdot (n-1)} \tag{3}$$

Where RI is the random consistency index to determine whether M_i is a consistency matrix or not. The value of RI is presented in Table 3.

Table 3
Values of the Random Index (RI)

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Source: (Saaty, 1977), (Bhushan and Rai, 2004)

The calculation processes of consistency checking (as well as the further weighting/calculation steps) of comparison matrices are done in Matlab. The value of $\lambda_{\max}$ and checking results of CR are listed in Table 4. The values are round to two decimals.

Table 4
$\lambda_{\max}$ and Value of CR of Each Comparison Matrix

matrix	M^*	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_{71}	M_{72}	M_{73}
$\lambda_{\max}$	7.74	8.92	3.09	4.08	2	2	3.09	3.07	3.09	3.05	3.07
CR	0.09	0.09	0.08	0.03	0	0	0.07	0.06	0.08	0.05	0.06

By adjustment and calibration, all the checked $/ CR < 0.1 /$, consistency of established comparison matrices are acceptable. Then the corresponding normalized right eigenvector regarding the principal eigenvalue $\lambda_{\max}$ of comparison matrix are calculated as local weight of each criterion. First step is to normalize the corresponding eigenvector W_i of the principal eigenvalue $\lambda_{\max}$. The principal eigenvalue $\lambda_{\max}$ and the corresponding normalized right eigenvector W_i of the comparison matrix present the relative importance of the various criteria being compared. The elements of the normalized eigenvector (each $/ w_{ij} / \sum_{j=1}^{i} w_{ij}$ /) are local weights with respect to the criteria or sub-criteria. The corresponding global weight (aggregated weight) of each criterion is multiplication of the corresponding local weights (e.g., regarding the service quality Q, the weight of criteria C_1 is W_1, the local weight of criterion C_{11} regarding C_1 is w_1, then the global weight of C_{11} regarding the service quality Q is / $w_{11} = W_1 \times w_1$ /).

$$W_i = \begin{bmatrix} \frac{w_{i1}}{\sum_{j=1}^{i} w_{ij}} \\ \frac{w_{i2}}{\sum_{j=1}^{i} w_{ij}} \\ \vdots \\ \frac{w_{ij}}{\sum_{j=1}^{i} w_{ij}} \end{bmatrix}$$

3.3. Establishing the Calculation Method for Aggregated Quality Value

The service quality assessment method is completed with the corresponding global weights of the first level criteria group and the second level criteria. In the further application step, the criteria group C_i and criteria C_{ij} act as evaluation index to be scored (graded) in order to obtain the aggregated service quality value Q. The aggregated single value is easier to be compared when supporting for decision making. The aggregated quality value Q calculated by the weights W_i and scores S_i of criteria group C_i is presented with equation (4). The aggregated quality value Q calculated by the weights w_{ij} and scores s_{ij} of criteria C_{ij} is presented with equation (5).

$$Q = W_1 \cdot S_1 + W_2 \cdot S_2 + \cdots + W_7 \cdot S_7 \tag{4}$$

And

$$Q = w_{11} \cdot s_{11} + w_{12} \cdot s_{12} + \cdots + w_{73} \cdot s_{73} \tag{5}$$

The weights and scores of third level sub-criteria are not taken into calculation directly. Only C_7 is developed with sub-criteria, these relevant weights ($w_{7j.k}$) and scores ($s_{7j.k}$) are to be used for analysis purpose (e.g. the potential service improvement aspects) in service feedback phase (e.g. survey of service satisfaction).

4. Results and Discussion

The global weight table of first level criteria group C_i and second level criteria C_{ij} are as most relevant results presented in Table 5. The entire quality criteria with aggregated (global) weights are listed, C_1 Speciality (0.27), C_3 Accessibility (0.11), C_4 Information (0.20) and C_7 Comfort (0.24) criteria groups are considered with higher weights. The results adhere to the characteristics of this new service, which are highlighted with Speciality. The mobility system of future may be a combination of transportation and information system, the real-time information is the backbone of such mobility services. On the one hand, the interoperability among the service providers and traffic control is realized and enhanced by the real-time information. On the other hand, the acquisition of real-time information is essential for the users, especially the real-time traffic condition reminder. The criteria C_{11} integrated smart phone application (0.07), C_{17} individual mini pod transit (0.07), C_{41} real-time information (0.19), C_{52} punctuality (0.06), C_{71} supplementary service (0.07) and C_{72} vehicle condition (0.14) are assigned with relatively higher weights. The MaaS operator, the service providers and the users are connected by the smartphone application. PFT service is regarded as opportunity to attract more private car users to try this 'semi-public' mobility service (private service experience in public vehicle). Service loyalty towards users could be affected by the punctuality. Connected AVs are in a wireless network, such wifi and charging (phone) requirement of users may have opportunities to be managed.
Considering the decimal form of the calculated weights and the potential aggregated service quality value Q, the importance of each criterion (C_i, C_{ij}) is 10 points when scoring the service quality criteria towards the evaluation index (criteria) system. Following one evaluation example is presented. The used numerical values have been determined by assumptions and are applied only for demonstration purposes.
Scoring example of criteria groups (C_1 to C_7) and second level criteria (C_{11} to C_{73}) is presented in Table 6. Scoring/grading of criteria groups is a kind of fuzzy scoring, because detailed description or judging criteria do not support this process. As the scored numerical values are according to experience more, the result is as a fuzzy/estimated value. According to equation (4), the aggregated quality value /Q_1 = 8.03/. Different scoring values may occur (e.g. criterion with higher weight may be scored with lower value) scoring for second level criteria. With detailed judging criteria description support (Table 1), not only according to subjective experience, but more objective score value is to be offered. For example, criteria group C_1 Speciality is scored according to general experience without knowing details of this new service. By supported by C_{11} to C_{18} scoring is clear about the quality criteria (evaluation index): the smartphone application with integrated functions, the selection of travel fellow and seat position, the PFT service, etc. The evaluation is unfolded by the hierarchical level of assessment criteria (index) step by step. The more detailed third level sub-criteria are also possible to be established, but considering the time limitation of questionnaire survey, two or three level criteria are sufficient for operation and analysis purpose. According to equation (5), the aggregated service

quality value /Q_2 = 7.71/. 7 numerical values are in aggregation towards Q_1, 25 numerical values are in aggregation towards Q_2. From literature review, we also conclude that most quality assessment criteria (evaluation index system) applied three level evaluation method (e.g. Csonka and Csiszár, 2016; Jain *et al.*, 2014; Matijošius *et al.*, 2016; Barbosa *et al.*, 2017), such kind of three level assessment criteria is introduced as a comprehensive evaluation approach.

Table 5
Quality Criteria with Global Weights

	Q : **Service quality**		
	Sign	**Criteria**	**Weight**
C_1 Speciality (0.27)	C_{11}	integrated smart phone application	**0.07**
	C_{12}	travel fellow selection	0.01
	C_{13}	seat position selection	0.02
	C_{14}	application reminder	0.01
	C_{15}	personalization	0.04
	C_{16}	environment impact	0.04
	C_{17}	individual mini pod transit	**0.07**
	C_{18}	dynamic pricing	0.01
C_2 Availability (0.05)	C_{21}	operating hours	0.01
	C_{22}	frequency	0.01
	C_{23}	average distance to reach the service (GRT)	0.03
C_3 Accessibility (0.11)	C_{31}	ticketing and payment	0.04
	C_{32}	ticket validation	0.03
	C_{33}	booking	0.01
	C_{34}	tariff structure	0.03
C_4 Information (0.20)	C_{41}	real-time information	**0.19**
	C_{42}	feedback	0.01
C_5 Time (0.07)	C_{51}	estimated time	0.01
	C_{52}	punctuality	**0.06**
C_6 User care (0.06)	C_{61}	emergency device	0.03
	C_{62}	user support service by personnel	0.02
	C_{63}	special care (for mobility-impaired)	0.01
C_7 Comfort (0.24)	C_{71}	supplementary service	**0.07**
	C_{72}	vehicle condition	**0.14**
	C_{73}	waiting station (GRT)	0.03

The first research question, which quality assessment criteria are to be introduced, is answered by Table 1. The second research question, how are the weights of criteria to be determined, is answered by the sub-section 3.2 and the results presented in Table 5. However, the third research question, what are the application opportunities of this assessment method, is to be answered and discussed as following.

The aggregated Q values are to be regarded as the expectations/attitudes towards this new service (the MaaS based on AVs). The expected service quality evaluation survey among several groups (e.g. experts of transportation engineering, potential service providers, MaaS operator, users, it is assumed that they are all potential end-users of this service) are to be conducted as further application work to collect data. The expectation of service quality Q (mean value) is to be revealed by calculation result. These mean values are to be grouped (e.g. quality mean value of experts, quality mean value of service providers), an expected quality value interval is to be set in order to support decision making (e.g. a reference towards the targeted quality level) when planning such a new service. This assessment method is also applicable in the users' satisfaction survey (service implementation and perception phase). The design of user satisfaction questionnaire and analysis of survey results could be supported by established assessment method.

Establishing a quality evaluation index (criteria) system for this new service and present a method to calculate the aggregated, (expected) quality value is the aim of our work, but it is not the goal of service quality assessment. It is more valued to decrease the gap between the expected and perceived service quality in future application phases. Further applicable improvement solution is to be revealed via scoring/grades analysis (e.g. criterion with low scoring value is the improvement opportunity), in order to deliver a high level of user satisfied service.

Table 6

Quality Score Aggregated by C_i and C_{ij}

Criteria group and Weight (W_i)		**Q_1 = 8.03**	**Q : Service quality**			**Q_2 = 7.71**
	Scoring	**Score (S_i)**	**Sign**	**Scoring**	**Weight (w_{ij})**	**Score (s_{ij})**
C_1 Speciality (0.27)	9	**2.43**	C_{11}	9	**0.07**	**0.63**
			C_{12}	6	0.01	0.06
			C_{13}	5	0.02	0.10
			C_{14}	5	0.01	0.05
			C_{15}	6	0.04	0.24
			C_{16}	8	0.04	0.32
			C_{17}	7	**0.07**	**0.49**
			C_{18}	7	0.01	0.07
C_2 Availability (0.05)	7	0.35	C_{21}	6	0.01	0.06
			C_{22}	7	0.01	0.07
			C_{23}	5	0.03	0.15
C_3 Accessibility (0.11)	8	**0.88**	C_{31}	8	0.04	0.32
			C_{32}	8	0.03	0.24
			C_{33}	7	0.01	0.07
			C_{34}	8	0.03	0.24
C_4 Information (0.20)	8	**1.6**	C_{41}	9	**0.19**	**1.71**
			C_{42}	5	0.01	0.05
C_5 Time (0.07)	7	0.49	C_{51}	8	0.01	0.08
			C_{52}	9	**0.06**	**0.54**
C_6 User care (0.06)	6	0.36	C_{61}	8	0.03	0.24
			C_{62}	6	0.02	0.12
			C_{63}	8	0.01	0.08
C_7 Comfort (0.24)	8	**1.92**	C_{71}	4	**0.07**	**0.28**
			C_{72}	9	**0.14**	**1.26**
			C_{73}	8	0.03	0.24

5. Conclusion

The existing MaaS projects are under development or in implementation phase, the MaaS based on AVs is considered as the future solution. Integration of transportation modes has been emphasized for long time and driverless characteristic of vehicles is a new advantage regarding information management processes. The MaaS concept is incorporated with AVs to provide a high-quality mobility service, in order to attract more private car users to use the high-quality, personalized public transportation service.

The main contribution and novelty of our work was that we identified the quality criteria and introduced the calculated weights for this new service. AHP method was applied. The elaborated assessment method is applicable for decision making when planning and introducing such a new service.

We faced, as a lesson learnt, it was difficult to scale the subjective quality criteria, as well as assigned them with appropriate weights.

The further research directions are:

- assessment and comparison of existing MaaS models by applying multicriteria analysis methods,
- elaboration of information system model for autonomous mini pod service.

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