Information Management for Mobility-as-a-Service Based on Autonomous Vehicles

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Abstract: The Mobility-as-a-Service (MaaS) concept is proposed to facilitate integration of transport modes regarding personalized journey planning and payment. When conventional vehicles are replaced by autonomous road vehicles (AVs) in MaaS, the information management processes alter significantly. The research questions were: how to model, design, and operate the new mobility services based on AVs in MaaS framework, focusing on information management. System engineering (SE) principles were applied. We elaborated the system structure model, the data model and the operational model. The connections among models were also presented. A dynamic pricing method was introduced to conciliate the demand and capacity as well as to calculate the service fee in MaaS. The theoretical results are applicable during design of the new service.

Keywords: information management, Mobility-as-a-Service, autonomous vehicles, dynamic pricing

Introduction

Mobility-as-a-Service (MaaS) is a data-driven, user-centric, integrated mobility service, which is developed for transport modes integration, to satisfy users' expectations of customized journey. Journey planning, booking, ticketing and payment processes for an entire multimodal journey are conducted through a single interface via smart phones [1] [2]. Autonomous road vehicles (AVs) are able for high-level sensing of the environment and control movements without a human driver, which are also designated as driverless, self-driving, or robotic cars [3]. AVs will replace conventional vehicles in transportation systems. Electricity or any other clean energy source are used to facilitate sustainable development. As AVs are equipped with artificial intelligence (AI), their roles will alter information management processes significantly.

In this paper, we focused on the information management issues for MaaS based on AVs. The research questions are:

- What kinds of new mobility services are to be introduced?
- How is the information system to be modelled?
- How can be dynamic pricing applied?

The reminder of the paper is structured as follows. State of the art is summarized in Section 1. In Section 2, mobility service types based on AVs are defined. The elaborted system structure model and data model are presented in Section 3. In Section 4, the operational model together with a calculation method for dynamic pricing are described. The paper is completed by conclusions, including further research directions.

1. State of the art

MaaS is seamless, door-to-door mobility service regarding multimodal journey, which is a highlighted topic related to sustainable mobility [4]. MaaS is better provided under hypothesis that all transportation systems are integrated, using real-time data, and responding to a broad range of user priorities [1]. The main two characteristics of MaaS is mobility servitization and data sharing. The dynamic multi-service journey planner [2] provide customized journey planning according to users' preferences, which makes transportation as a service rather than only a derived demand. With MaaS, users may purchase mobility service from the service operator-MaaS operator, which is not like now from separate transport operators. MaaS operator cares about personalization and customization of provided mobility services [4]. With the rapid growth of smartphone users, mobility data collection and real-time data provision are available by support of applications [5]. Several MaaS projects already launched, e.g. Whim app in Helsinki, Qixxit in Germany, Beeline in Singapore, MaaS4EU project [6]. Autonomous vehicles may become one of the key technology of MaaS development, due to its automated dispatching process and saving human resources (drivers and dispatchers are eliminated). Shared mobility in MaaS facilicates a shift from car-ownership to car-usership.

An advanced variant of DRT transport mode that merges most of the so called transitional services (e.g. car-sharing, ride-sharing, ride-sourcing) was summarized in paper [7]. This mode is called Telematics-based Shared Demand Responsive Transportation (TS-DRT). The system structure and operational model of TS-DRT as well as a conceptual plan of a mobile application are elaborated in paper [8]. As conventional demand-responsive transportation modes require relatively long reservation process and mostly used for people with disabilities, in order to distinguish better, we call this new mode as Telematics-based, Shared, On Demand Transportation (TS-ODT).

AVs are controlled by computers, under support of advanced technologies (e.g. sensors, lasers, deep learning, machine vision) to react to the surrounding environment. They are able to run on not-separated paths. The user group of AVs may cover elders, children and people with disabilities who are not able to drive. They have opportunity to own self-driving cars or rather use shared mini AVs individually [9]. Google, Apple, Tesla, etc. are all competed in autonomous driving research area and announced plans to commercialize this technology [10]. As a campus has good practice environment, the feasibility of driveless taxi service on a 4.5-km campus road has been demonstrated at Seoul National University [11]. Because of high price of AVs, shared mobility services are proposed in order to share travel cost and optimize ridership [12]. If a cost-efficient shared-ownership [13] or a shared taxi model [14] could be built up on AVs, users may give up owning private expensive AVs. In our research, shared autonomous vehicles (SAVs) include mini (1 user), small (2-6 users) or medium (7-12 users) sized pods. Namely, SAVs are for first and last-mile solutions of mobility-on demand service, which could potentially complement public transportation networks [15]. By using AVs in transportation system, minimization of the number and severity of accidents, reduction in the environmental impacts and improvement of road traffic parameters (e.g. average travel time, traffic flow capacity) are expected as economic and social benefits [3]. However, several studies also show that AVs may cause congestions in the city. Furthermore, the transport policy, regulation and legal issues of AVs are also requested to be solved.

Dynamic pricing is an advanced pricing strategy. In order to provide price-worthy service for users according to on-demand situation, variable prices are applied instead of fixed prices. The essence of dynamic pricing in transportation is to conciliate demand and capacity, to minimize cost for users and maximize revenue for service operators. Dynamic pricing is already applied by on-demand ride-sourcing companies such as Uber, Lyft, etc. Uber provide dynamic pricing area map for drivers to get more passengers [16]. Dynamic pricing may be preferred in AVs approach for its up-to-date reasonable price calculation.

Several papers discussed about Mobility-on-Demand system or services based on AVs. They mainly focus only one component, process or aspect (e.g. service types, models for mobile application) [17]. Very limited paper addresses research of SAVs from a system view. As implementation of MaaS concept is still in emerging phase, only few papers combine it with AVs. Therefore, our research is relatively new, we merge SAVs in MaaS framework, in order to present a systematic overview of information management processes in such an integrated mobility system. Namely, we have introduced new mobility service types for MaaS based on AVs, the system structure model, data model and operational model were also elaborated, connections among models were presented by identification of input and output data of functions.

2. Mobility service types based on AVs

Car ownership is not so relevant in the future, users care more about the quality of mobility services. In future MaaS, the automated conventional public transportation (e.g. autonomous bus and tram or automated metro) are used for large volume passenger transit. AVs are used mainly for first or last-mile, point-to-point service or feeder service to conventional public transportation. As MaaS has the potential to decrease dependence on private vehicles, service types of MaaS based on AVs should be designed to merge as many transportation modes as possible. Proposed service types based on small or medium sized AVs [8] :

• Group Rapid Transit (GRT),

• Special Demand Responsive Transit (SDRT),

• Small Group Rapid Transit (SGRT),

• Personal Flexible Transit (PFT).

The types are illustrated approximately according to service price and number of passengers per vehicle in Fig.1.

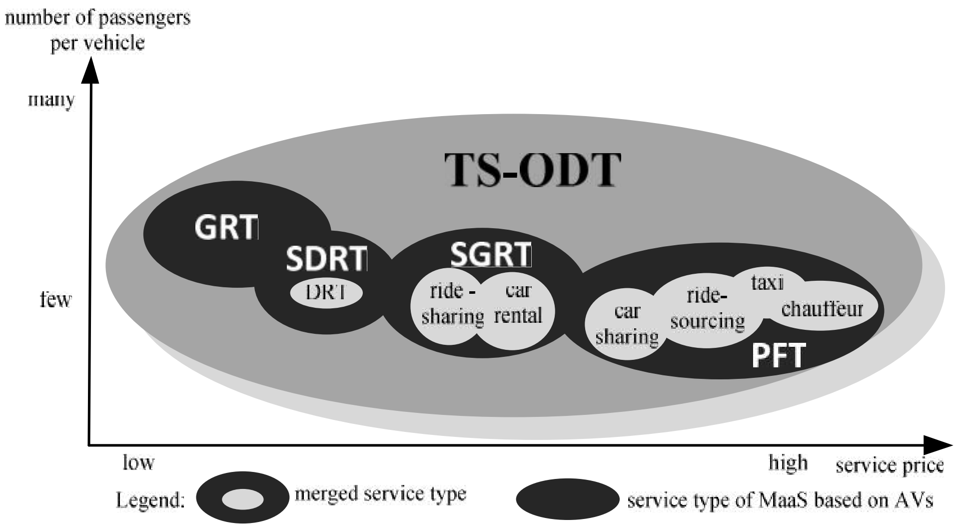

Figure 1. Service types in MaaS based on AVs

Namely, the service fee of GRT is the lowest one, following are SDRT and SGRT, and charge of PFT is the highest. The service types are described in Table 1.

Table 1. Description of service types

service type	capacity	route	time table	other attributes
PFT	mini pod, only for 1 user	flexible	×	point-to-point service, fast transit, high comfort level.
SGRT	small, 2-6 user	semi-flexible	×	point-to-point service, it can be used as ride-sharing service or for car-rental purpose.
SDRT	small, 2-6 user	semi-flexible	×	special feeder service, for people with disabilities, with extra equipment, point-to-point service.
GRT	mdium, 7-12 user	fix	√	feeder service to the conventional public transportation.

These four service types are all sharable and require reservation. PFT service is shared among users after each other, but during one task, there is only one user on vehicle for its mini capacity. In case of SGRT and SDRT services, users can choose whether to share vehicle or not with unknown travelers. GRT is a feeder service to conventional public transportation; accordingly, users must share vehicles when using this service.

PFT, the mini pod service can satisfy travel demand for only one user, but providing fast and high comfort level. For example, equal to separated working space is provided and may be preferred by business users during journey. It guarantees the comfort journey for elder users. In case of busy parents who do not have enough time, this service can pick up children to go and come from school (kindergarten) as well. For people with disabilities, they may feel more freedom in separated private space, etc.

SGRT can be used if the travel demand is higher (e.g. family, friends, tourists). Ride-sharing service means small group (less than 6 users) travel in the same vehicle during one journey and the cost are shared. Because users may require to wait other users boarding/alighting, SGRT service is semi-flexible. But depending on the capacity of the vehicle, the separated seat space is larger and comfort level is higher. Tourists are not familiar with visited city and may prefer this service type, AVs can take them directly to the tourists' attractions. Car rental service means a vehicle rented by one user, no sharing with strangers. For instance, one family member can rent a medium AV for family trip during weekends.

GRT is timetable and fixed route based service, for medium passenger volume transit. Considering service quality, passengers are not allowed to stand on the vehicles, reservation guarantees the seat. For example, GRT can be used as school bus service or work travel plan service.

Although both SGRT and GRT can provide separated seat space (e.g. wheelchair space) for people with disabilities, it is essential to have totally separated service type SDRT, considering psychological factors. Those AVs served for SDRT are equipped with extra devices, e.g. ramp for wheelchair which can stretch out and draw back automatically, voice-based guiding system for blind people boarding, face recognition camera or eye tracking device for individuals without arms to enter the vehicle, etc. People with disabilities can apply for human staff help as well.

3. System model of MaaS based on AVs

We have modelled the system structure to reveal the components and connections between them. Top-down approach was applied. The main data groups were identified. As data keep components together, a simplified data model was developed for information(data) management purpose.

3.1 System structure model

The main components are shown in the system structure model (Fig. 2), the connections are represented by arrows. The functions requiring a certain connection (data flow) are represented by numbers. One number may be marked on several arrows, if more than two components cooperate in one function. The main components are:

U: Users [with smartphones]

M: MaaS operator

T: Transport operators

A: AVs

D: Data providers

C: Integrated management center

Users (U) together with smart phones are considered as 'smart' travellers in the mobility system. Registration is mandatory. Users' profiles and their preferences are set for MaaS operator to plan personalized journey. Reservation is obligatory. After reservation, user reveives a digital ticket and it is used during the whole journey (e.g. scanning the QR code, using NFC technology). Smart phone has important role in all processes (planning, booking, ticketing, payment, etc.).

MaaS Operator (M) acts as an intermediary between transport operators and users, by booking (or buying) capacity from the former and selling it to the latter [2]. It also acts as money transfer intermediary who will receive payments from the users and split these payments and transfer to respective transport operators. The dynamic multimodal journey planner mobile application is provided by MaaS operator, the personalization and recommendation function of planner conciliates demand and supply. For users (as demand side), booking (reservation), ticketing and payment processes are realized by this application, The MaaS operator (as supply side) proposes the ideal combination of transport modes by knowing real-time data of traffic condition and customization.

Transport operators (T) provide mobility service. They can be conventional public transport operators and the service operator of AVs. MaaS may cover urban trips, inter-city and cross-boarder journeys. We mainly focus on the service operator of AVs, this operator manages AVs (e.g. vehicle checking, maintenance, 'dispatching'-information exchange).

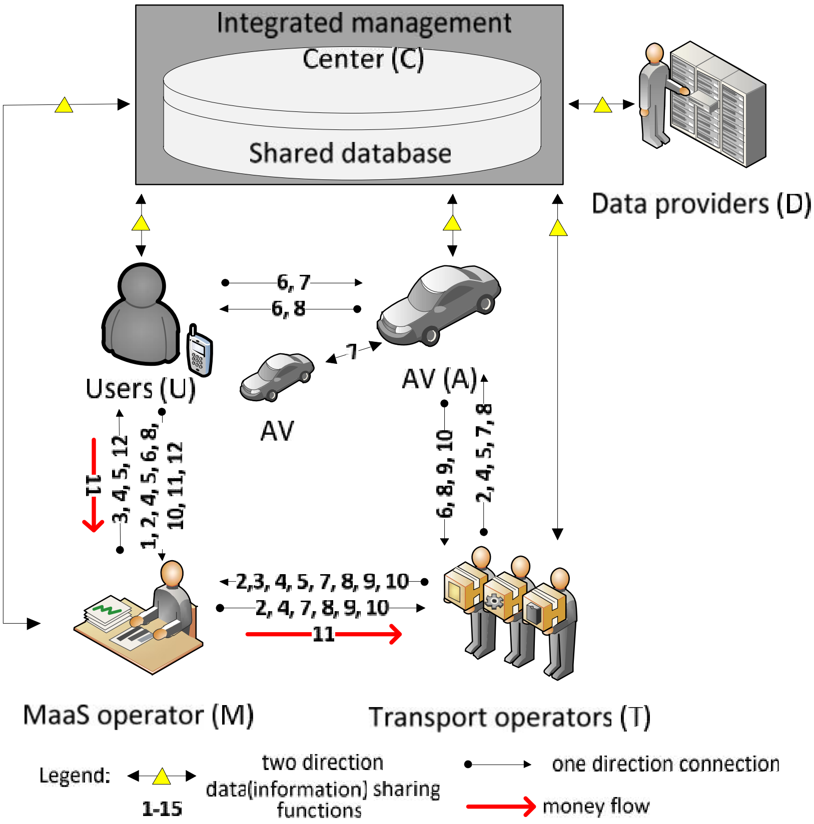

Figure 2. System structure model of MaaS based on AVs

In MaaS based on AVs system, all the vehicles are connected to an information network. The communication among vehicles-to-everything (everything refer to vehicle, infrastructure, pedestrian, etc.) is described by Internet of Vehicles (from Internet of Things). Furthermore, except charging and maintenance time, AVs can work day and night without working time limitation. Intelligent dispatching algorithms can optimize tasks and reduce the empty runs (e.g. similarly as dispatching algorithm of Uber). AVs are easier to be managed as all the processes are controlled by algorithms via machine-to-machine information management, more efficient and reliable than human-machine processes.

Data providers (D) act as the third party external data service providers to offer data. They are not connected directly with other components. Data are offered through Integrated management center (C). The following sources may act as data providers: map service providers, weather information providers, traffic control operators, users (e.g. via social media), etc.

Integrated management center (C) is responsible for the mobility system management. In our work, we focus on the integrated information management purpose. Huge shared cloud databases are used to store, process and classify all type of service data and Cloud Storage and Share service may be offered. The integrated database is connected with all the other components. Processed and classified data can be offered to data providers again. In this case, bi-directional so called Data-as-a-Service is realized between D and C.

The following data source of data groups are stored in databases of C:

1) Data from users:

   1.1) MaaS account data; 1.2) data of preferences; 1.3) data of characteristics; 1.4) data record of mobility traces; 1.5) data from feedback; 1.6) data from social media (connected links with application. e.g. recommendation); etc.

2) Data from MaaS operator:

2.1) reservation data; 2.2) data record of demand-capacity checking process; 2.3) data record of demand-capacity coordination process; 2.4) data record of payment process; etc.

3) Data from Transportation operators (AVs):

3.1) data record of vehicle dispatching; 3.2) data record of vehicle charging and maintenance; etc.

4) Data of/ from AVs:

4.1) basic data of vehicles; 4.2) real-time data of vehicle tracking; 4.3) data from Internet-of-Vehicles; 4.4) real-time data of vehicle condition (e.g. charging requirement); etc.

5) Other source (e.g. from traffic control center, from weather bureau):

5.1) transport network data; 5.2) public transport timetables, stations; 5.3) real-time traffic condition data; 5.4) weather data; 5.5) environmental data; etc.

3.2 Data model

The MaaS operator, transport operators and data providers all have their own databases, as we focused on the operational processes of information management, we elaborated the data model for MaaS operator, which maps the operation of AVs. Data source of input and output data are from Integrated management center and Data providers. Only the entities as tables are presented, without the attributes (Fig. 3). The connections among entities are represented by arrows. This initial model is used during elaboration of operational functions.

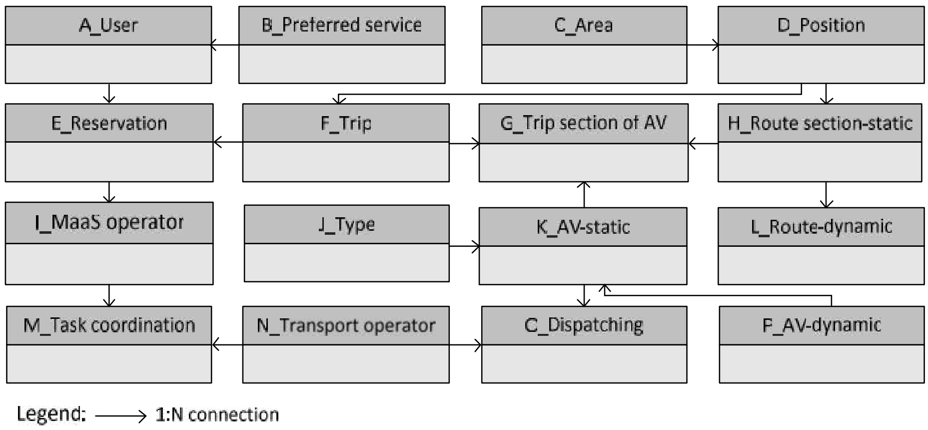

Figure 3. Simplified database structure

Section-oriented approach has been applied to highlight the trip section of users. E.g. route length, sharing factor are recorded to calculate individual fee for SAV section. Vehicle capacity affects the reservation, therefore, number of remaining seats and level of battery are recorded in AV-dynamic table for operation purpose. Tracking data of vehicles are recorded by Position table connected with other trip related tables. Several dynamic data (e.g. weather factor, road condition) are recorded by Route-dynamic table.

4. System operation of MaaS based on AVs

As our research mainly focused on the information management processes, the system operational model and dynamic pricing calculation method were elaborated. Input and output data (groups) were also identified for the functions.

4.1 Operational model

In order to operate such a mobility system, the following functions are proposed. The operation process is divided into four parts according to phases of journey: before journey, journey planning, during journey and after journey. Each part has their own main functions, which are presented as follows. The operational model was elaborated and shown in Fig. 4.

1. registration. Real-name registration and user bank account (credit card) providing is obligatory. Personal preferences and individual characteristics setting support to form user's profile. Individual mobility traces and system feedback as well as user's profile are updated along with each journey. Detailed statistical analysis about above data (information) faciliates customized journey planning.

2. journey (planning) request, D-C (demand-capacity) checking. User sends his/her personal journey request (e.g. from where to where, departure time and arrival time). MaaS operator does not buy all the capacity from the transport operators, MaaS operator check available capacity first for the user with specific route. If MaaS operator does not have enough capacity, then transport operators check whether extra vehicle capacity is available to fulfill the current demand. During this process, condition information of possible vehicles are also checked (e.g. maintenance requirement).

3. options providing. MaaS operator provides several options with estimated journey time and cost via journey planner. The options are combinations of different transport modes. The order of the options is proposed depending on the user preferences, travel habits (historical data), traffic conditions, etc.

4. choice confirm, task coordination. User confirms his/her choice, MaaS operator coordinates capacity and demand. Maas operator and transport operators confirm with each other and release the booking. The result of task coordintion are also informed users. For example, the vehicle brand, plate number, estimated arrival time and position, etc. are offered regarding trip sections of AVs.

5. ticket, vehicle confirmation. MaaS operator sends a digital ticket to user's smartphone; this is a certification of purchased service. Specific transport operator coordinates the task and confirms vehicle. For example, check AV (e.g. battery level, cleanness of vehicles, air-condition and entertainment devices) and dispatch AV (information exchange) to wait at the right place.

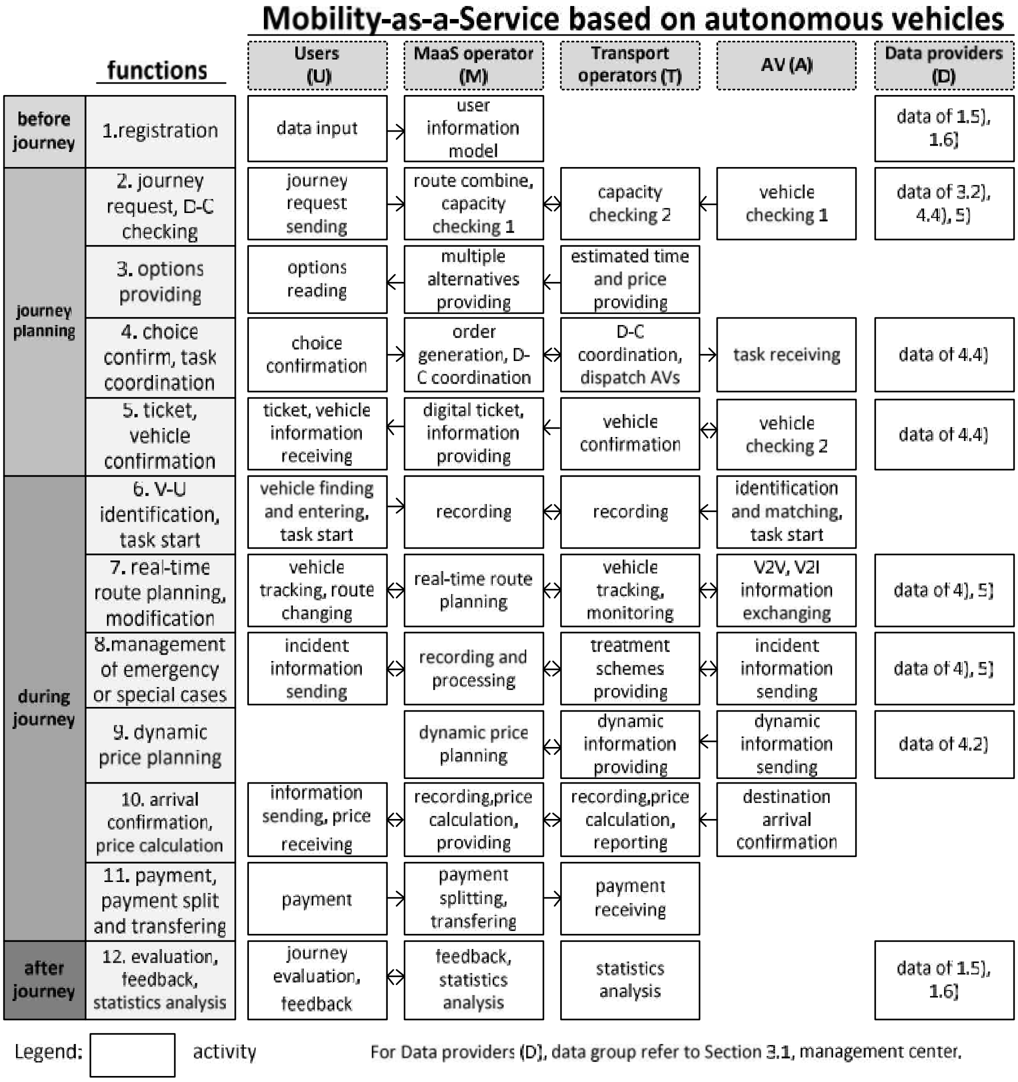

Figure 4. Operational model of MaaS based on AVs

6. V-U (vehicle-user) identification, task start. One way to find ordered vehicle is using Bluetooth matching technique to match user and vehicle. (Smart phone and vehicle can be connected, to provide a real-time map and navigation for user to find the vehicle). Fingerprint identification, QR code scanning can be used to open the door.

7. real-time route planning, modification. Because of the dynamic traffic situation, the route can be re-planned by journey planner when each task starts. Vehicle is tracked and monitored during the journey. For AVs, V2V and V2I information exchange is applied during the whole journey.

8. management of emergency or special cases. An extreme situation always has probability to happen. For instance:

Collision of AVs: the primary treatment is always to protect the users. AV has automatic emergency alarm device (e-call) to send information to the emergency and management center, to let the relevant operator react.

Smoking of users: smoking is forbidden in the vehicles. If someone breaks the rule, the sensor on the vehicle sends information to the MaaS operator, the credit score is decreased; furthermore, this user is punished.

9. dynamic pricing planning. Relevant data are collected and processed for each covered section of journey. The variable and parameters for service fee calculation of AVs are determined latter, correspondences among parameters are also presented. Value of variable and value of variable parameters (e.g. time-varying parameters) are recorded by this function.

10. arrival confirmation, price calculation. Task ending. Price is calculated considering many factors. (e.g. sharing factor, peak time factor)

11. payment, payment split and transferring. Users pay for one entire journey via the smartphone. MaaS operator split payment and transfer each part to the specific transport operators.

12. evaluation, feedback, statistics analysis. Both MaaS operator and transport operators conduct statistics analysis in order to improve quality of service.

Input and output data groups (or data source of data groups) of functions are summarized in Table 2. Data tables (see capital letters in data model) and external data offered by data providers (refer to Section 3.1) are used by the functions.

Table 2. Input and output data

Input data	function	Output data
A, B, 1.2), 1.3), 1.6□	1. registration	A, 1.1)
A, C, D, I, K, N, 3.2), 4.4), 5)	2. journey request, D-C checking	M, 2.2)
I, M, N	3. options providing	2.3)
A, F, I, K, N, 4.4	4. choice confirm, task coordination	E, M
A, F, I, K, N, 4.4	5. ticket, vehicle confirmation	F, O
A, G, K	6. V-U identification, task start	H
I, K, P, 4), 5)	7. real-time route planning, modification	P, 4.2), 4.3), 4.4), 1.4)
K, P, 4), 5)	8. management of emergency or special cases	K, P, 4.4)
G, I, K, N	9. dynamic pricing planning	G
A, C, D, F, G, K, I, N, 4.2	10. arrival confirmation, price calculation	F, G
A, F, I, N	11. payment, payment split and transfering	2.4)
A, F, 1.5), 1.6)	12. evaluation, feedback, statistics analysis	1.5), 1.6)

4.2 Calculation method for dynamic pricing

Price is a tool to conciliate demand and supply. A price-worthy service is preferred by users and should be offered by operators. The MaaS operator cooperates with several transport operators and the trip sections are charged in different way. For example, section of conventional public transportation is different from AV section. Users are familiar with former one but may have expectation towards the latter one: the flexible and convenient new AV service should be charged reasonably considering service quality aspects (e.g. users may be charged differently regarding several parameters). Therefore, function of dynamic pricing was analysed and a calculation method has been developed. A general calculation method (main principles) is presented; the exact numerical value of parameters are not determined. The division of accurate value interval of each parameter are further research work. The first step approach aims to categorize the main parameters which should be taken into the dynamic pricing process. Parameters are defined in Table 3.

Basic price m_0 is price for vehicle running per kilometer:

$$m_{PFT}, m_{SGRT}, m_{SDRT}, m_{GRT}, \text{and } m_{PFT} > m_{SGRT} > m_{SDRT} > m_{GRT} \quad (1)$$

Real travel distance d is recorded as route length.

The main principle of service fee calculation for trip section of AVs is:

$$\mathrm{y = kx, where\ k \neq 0.} \quad (2)$$

y: price of trip section of AV.

$\mathrm{x} = m_0 \cdot d, d\ is\ the\ main\ variable.$

$k = \prod F_{ki}, k = 1,2,3,\cdots 6, i = 1,2,3.\ F_{ki}\ are\ parameters.$

F_{ki} are variable parameters, which can also be regarded as ’variables’, but in case $\mathrm{x} = m_0 \cdot d$ mainly determine the price of trip, F_{ki} slightly modify the final results, therefore, we have determined that the following factors are parameters.

Table 3. Parameters in dynamic pricing

Category	Sign	Parameters	Sign	Explanation	PFT	SGRT	SDRT	GRT
Capacity	F_1	seating capacity factor	F_1	number of remaining seats	√	√	√	×
Sustainability	F_2	sharing factor	F_2	shared service or not	×	√	√	√
Spatiality	F_3	area factor	F_{31}	suburban/ urban area	√	√	√	×
		remote factor	F_{32}	long distance trip	√	√	√	×
Temporality	F_4	period factor	F_{41}	daily or night trip	√	√	√	×
		peak time factor	F_{42}	peak time	√	√	√	×
		delay factor	F_{43}	vehicle delay	√	√	√	×
Discount	F_5	frequent/elder/student /disabled factor	F_5	discount for user groups	√	√	√	√
Quality	F_6	seat-selection factor	F_{61}	seat place choice	×	√	√	√
		service unsatisfied factor	F_{62}	depends on situation	√	√	√	×

Similar as airline service, price is affected by number of remaining seats: seating capacity factor. When AVs are used for small group ride-sharing service (e.g. SGRT, SDRT), total journey costs are shared among strangers regarding sharing factor. Basic price m_0 in suburban area is slightly higher than in urban area. In order to balance the low demand and high operation costs, area factor is introduced. Trip section of AVs are mainly used for short and medium distance travel, in case long distance, extra fee (calculate with remote factor) are considered (e.g. due to charging, redistribution). Night service is cheaper than daily one’. Division of time period is influenced by living behaviors of citizens and types of cities. Value of peak time factor may be determined by its dynamic charateristics (real road congestion situation reflect the peak time). If service (AV) delays, user receive some ’discount’ (count as delay factor). For frequent/ elder/student/disabled user groups, discount factor is counted. Such discount types are already applied in public transportation (except frequent factor). As TS-ODT merges pubic and private transportation modes, those discount types are still provided. Frequent users can get discount according to frequent factor. One user can only take one discount category (generally take the maximal one), no multiple discounts. In medium sized AVs, users can choose their seat: near window, near door, working-table seat space, or even separated seat space for one user, choice is counted as seat-selection factor. When they choose seat location, they can also see information of surrounding passengers, it means users can choose travel fellows (e.g. young ladies may prefer traveling with female). Service unsatisfied factor may be counted if: vehicle is not clean, the waiting stop is not clean, the smell in the vehicle is not good, air-condition or entertainment device do not work, etc.

Considering all above parameters, a dynamic price calculation method was provided:

$$\text{price} = \text{trip sections of conventional PuT} + \text{trip sections of AVs} \tag{3}$$

PUT: public transportation

Price for each trip section of AV was calculated and then summed up:

$$\text{price} = \text{trip sections of conventional PuT} + \sum \left(m_0 \cdot d \cdot \prod F_{ki} \right)$$

$$\text{where } k = 1, 2, \cdots, 6.\ i = 1, 2, 3.\ \text{if } F_{ki} \text{ does not exist, then } F_{ki} = 1. \tag{4}$$

'√' and '×' (in Table. 3) provide information whether the given parameter is considered or not at the service types. '√': take the value of parameter during calculation; '×': take the value of 1.

A relatively simple method for service fee calculation was presented by equation (4). Parameters slightly change the final trip price compared with the estimated one.

Conclusions

MaaS related projects are still in progress nowadays, MaaS based on AVs are considered as future solutions. Therefore, our research is innovative and useful for future innovation and development purpose. Integration of transportation modes is emphasized for long time, information management is one of the key issues. Supported by continuous development of Deep learning and Big data, personalized journey planning will be more precisely recommended and utilization of shared AVs may facilitate sustainable mobility.

The proposed new mobility service types, the information system model, the operational model, as well as a calculation method regarding dynamic pricing in order to provide a price-worthy service, are main contributions of our work. We faced, as a lesson learnt, it is complicated to model such information management processes for a new mobility service.

The key findings of our work are:

- demand-capacity coordination of MaaS based on AVs is an automatic process. Machine-to-machine coordination is a more reliable and efficient process,
- one-step service (including all functions related to a user) should be provided.

The further research of our work are as follows:

- the detailed process of demand-capacity coordination is to be elaborated,
- an assessment method for service quality analysis of MaaS based on AVs is to be developed.

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