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

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1. Introduction

With the fast development of global technology and economy, people expect much higher quality of travel services. Nowadays, transportation is not only a derived demand, but also is a kind of service. The concept 'Mobility-as-a-Service (MaaS)' is envisaged to provide a blueprint for transport integration, to offer people tailor made mobility solutions based on individual needs with easy access to the most appropriate transport mode or service [3]. In the future ITS [1] (Intelligent Transportation System), automated and autonomous vehicles (AVs) will replace the conventional vehicles to provide mobility services. Such mobility services provided by AVs are linked to MaaS concept. In my research, I mainly focus on the information management processes for a mobility system (MaaS) based on autonomous vehicles.

The research questions are:

- How can new mobility services be designed for the real needs of all people?
- What is the information system model for MaaS based on AVs?
- How is the mobility system operated and what are the information functions?
- How can be dynamic pricing applied in mobility services based on AVs?

Mobility service of AVs in MaaS is careful designed to care for the all people. The applied method is following top-down approach from system engineering principles [2], which is used for envisaging the system structure and operational model. Data modeling is used to elaborate the database structure. Dynamic pricing, which can influence the supply and demand, as one of the most important function is investigated in detail developing a price calculation method.

The aim of my research is to provide the information management processes of future mobility system based on AVs, to investigate the advantages of Mobility-as-a-Service using AVs, and to reveal the different aspects between services on AVs or conventional vehicles.

As my research mainly focus on the information management processes, the traffic control part is not presented, I use the results from traffic control indirectly.

The phases of the research process are illustrated in Fig. 1.

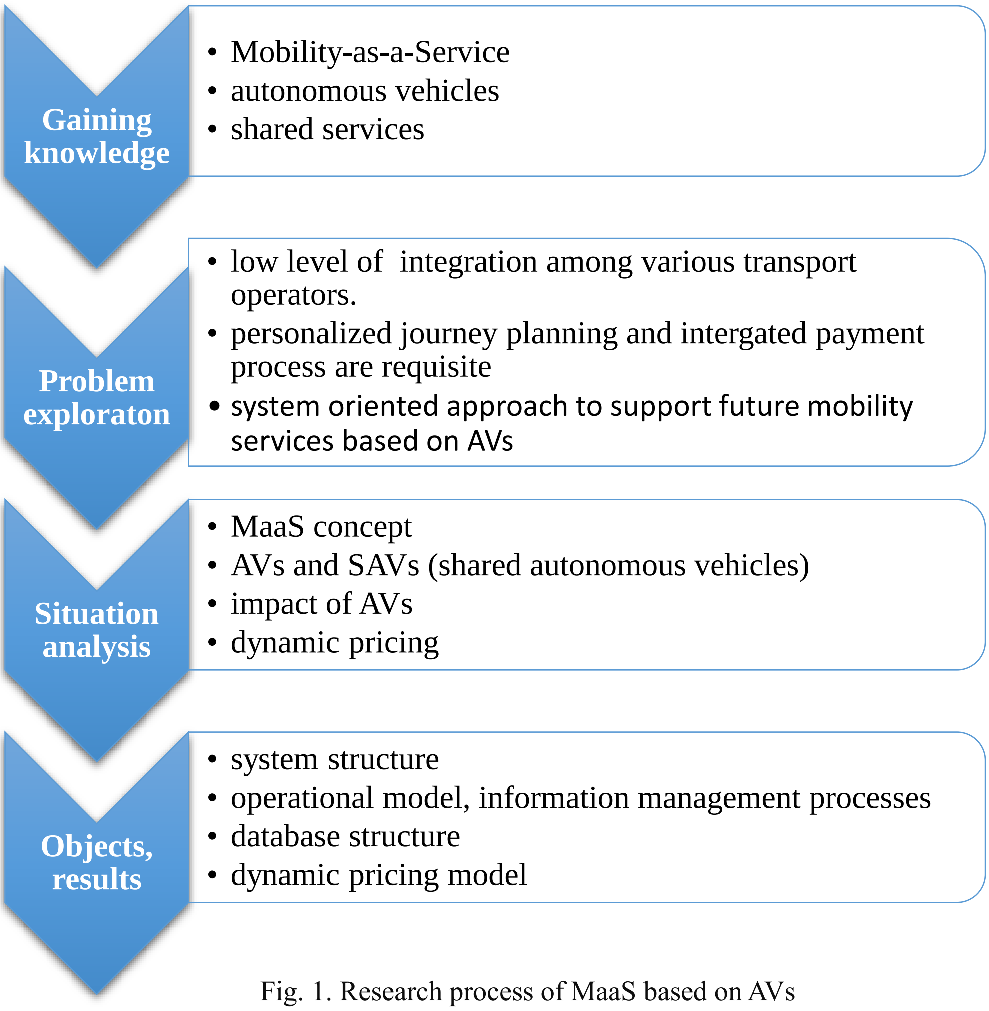

Fig. 1. Research process of MaaS based on AVs

The phases of the thesis structure are illustrated in Fig. 2

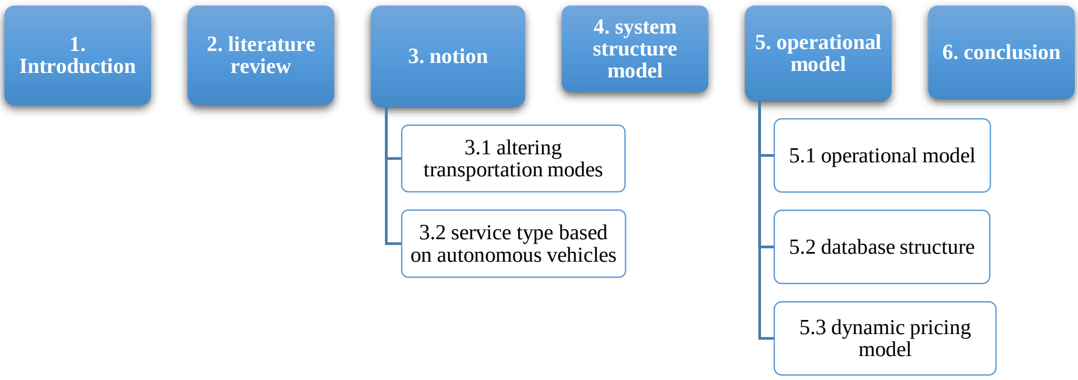

Fig. 2. Structure of the thesis

2. Literature review

Mobility-as-a-service is a seamless mobility system for passengers. From an end-user perspective, MaaS should be user centric, easy to plan, book and pay, as well as seamless during the actual trip, integrating all transport means and systems, using real-time data, and responding to a broad range of individual user priorities. MaaS also is supposed to be socially inclusive and permeable to national borders, transport modes, governance types, and other boundaries (cognition, cultures, languages, and currencies) [13]. The main two characteristics of MaaS is servitization and data sharing. MaaS operator integrates different kinds of transport modes in order to provide a valuable service, and sharing data based on user's mobility demands to help transport operators to improve their services [25]. In Europe, Easyway project, EDITS project, i-Tour project, MaaS4EU project, etc. realize mobility-as-a-service concept. An application (Whim) which is already provided by MaaS Global is available in Helsinki (Finland) and west midlands, UK [26]. In China, the concept related to MaaS is that this country prepares to build a 'one-stop' mobility service system, to realize 'one ticket to get to the destination' for passenger transport and 'one waybill to get to the last stop' for freight transport [27]. Autonomous vehicles become one of the key technology of MaaS development, for its convenient dispatch process (information exchange) and save human resources (driverless vehicles). MaaS stands for a change: MaaS has the inherent potential to decrease the use of private cars, as all types of mobility service are provided in MaaS to decrease or replace the using of private cars [13].

According to paper [21], self-driving vehicles can be defined as the vehicles which do not require any 'direct driver input, to control the steering, acceleration, and braking' of the vehicle, and do not require the driver to 'constantly monitor the roadway while operating in self-driving mode'. Autonomous vehicles are controlled by computers with artificial intelligence (AI) which are able to manage unexpected situations making individual decisions using cognitive capabilities and learning capacities. They are able to run on not-separated paths. The vehicles are mainly propelled by either battery or fuel-cell electricity [4]. It was not until 1980 that the first autonomous car was made by the Carnegie Mellon University's Narlab. Such developments were carried out by Mercedes Benz, which also produced what they called the first robotic car in the 1980s. Subsequent development incorporating laser distance sensing technologies (LIDAR) has been taken up in earnest by Google and others, including Baidu (an Internet company) in China. A number of European cities are also experimenting and introducing low-speed autonomous cars for public transportation, and autonomous vehicles are already in use in the military, mining and agricultural sectors. Google has announced that it may be 30 years before their autonomous cars could operate in all cities [5]. The development of fully autonomous vehicles still requires a relative long term, not only technology support is essential, but also the relevant politics and laws are supposed to be carried out, e.g. who will responsible for accidents of AVs?

Sharing economy, also termed collaborative consumption, refers to sharing of items and services, instead of owning all equipment by oneself [9]. It has been projected that shared autonomous vehicles could reduce the number of cars a city needs by 90%. Shared cars will avail people of many of their benefits of cars without the responsibilities of their ownership, to minimise the requirement for parking, provide improved mobility for those are unable to drive, and facilitate pooling (the seat sharing of cars) [5]. Several studies which relied on millennial surveys report that younger people are less keen to own private cars [8]. In a study by car sharing company Zipcar, it is reported that half of millennials interviewed say they would prefer public transport and car sharing systems to privately owned cars [22].

Shared mobility services which are served by the AVs are the using trend, in case that car-sharing, ride-sharing, and ride-sourcing services are welcomed. Shared autonomous vehicles (SAVs) provide inexpensive on-demand mobility services and could play a vital role in sustainable transportation systems, by providing convenient last-mile solutions, which could facilitate multimodality [6].

The major social impacts of AVs have been described in [7]: safer roads (less accidents), travel time reduction, improvement of energy efficiency and parking benefits. In [10], three scenarios analysis provide strong indication that the introduction of AVs alone cannot solve the problems our current mobility systems. We have to consider this new technology and its broad impact on a system level when aiming for a greener, more sustainable future for transportation. For example, it is possible to get AVs widely accepted as a shared vehicles or public transit modes, before they are entrenched as a new form of private mobility. According to [16], people can access self-driving vehicles in two ways: personal vehicle ownership or use as a shared vehicle. The results of this paper provide some of the first data on what types of people are likely to use self-driving vehicles. Wolfgang G. and Joseph M. S. [15] use the Swiss national transport model to simulate the impact of autonomous vehicles on accessibility of the Swiss municipalities. The results show that autonomous vehicles could cause another issue in accessibility. Moreover, the spatial distribution of the accessibility impacts implies that AVs favor urban sprawl and may render public transport superfluous except for dense urban areas.

Dynamic pricing, is a pricing strategy which applies variable prices instead of fixed prices. New and optimal prices are calculated and recalculated periodically, (e.g. every day or every hour). The essence of dynamic pricing is offering the right price to the right customer, at the right time, for the right product to increase the company's sales and margin [28]. Dynamic pricing is also practiced by on-demand transportation network companies such as Uber and Lyft. Uber provide dynamic pricing area map for drivers to get more passengers [29]. Paper [17] provide a linear dynamic pricing calculation method. Mine D. [28] lists some factors which can change price, such as local demand and supply, time, weather forecast, etc. In e-book [23], general rules are listed (e.g. use smart data to balance supply and demand, understand the rules for setting reasonable rates, etc.) for making a dynamic pricing.

In this section, literature review about MaaS, AVs, SAVs, main impacts of AVs and dynamic pricing were presented.

3. Notions

3.1 Altering transportation modes

In paper [3] and [17], authors provide the following definition: in the future, according to number of passengers and flexibility of transportation modes, the bicycle and bike sharing modes are unaltered. The individual motorized road transportation modes are based mostly on AVs and used for the most flexible travel purposes. The traditional public transportation (underground, train, tram, bus) is used only for large volume of passengers. The other modes (e.g. certain public transportation services, car-sharing, taxi, ridesharing, ride-sourcing) are merging into the new mode TS-DRT (Telematics-based, Shared, Demand Responsive Transportation), which are illustrated by Fig. 3.

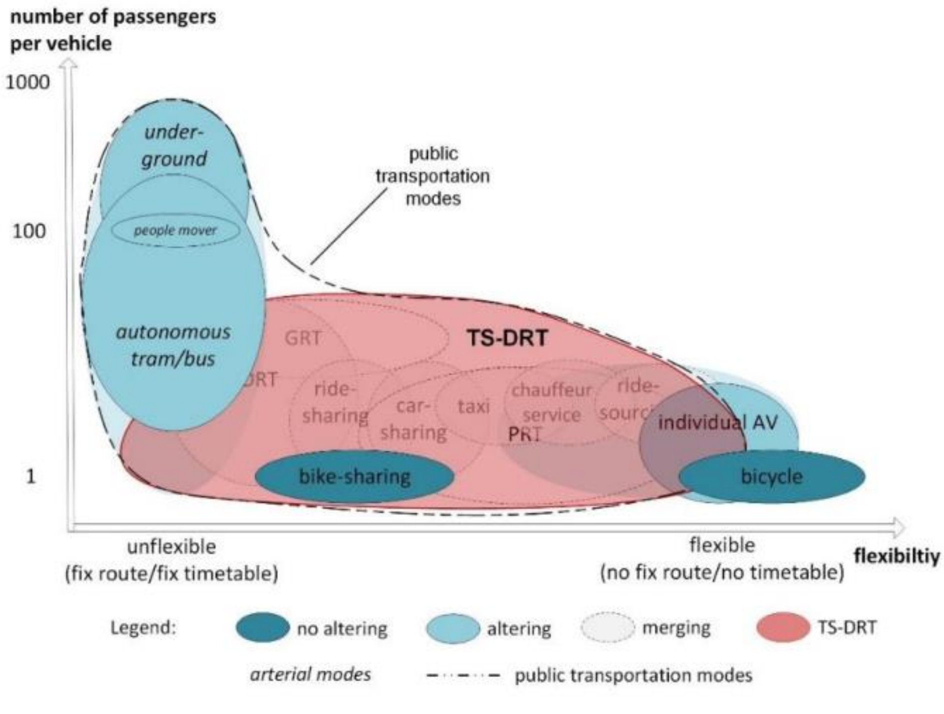

Fig. 1. TS-DRT on mobility 'palette'.

Fig. 3. Altering transportation modes (source: [14])

Car-sharing is a flexible car rental service for using a short period of time. Flexible cars are put around the street (parking area) or at the defined stations, users pick up cars after registration and reservation.

Ride-sharing is a shared journey cost service. In case of intercity journey or long-distance journey, drivers offer journey routes (through online website or application) and passengers search for journeys, after finding a match they contact each other to arrange details for the journeys (e.g. cost, meeting points, etc.) Then they meet and carry out their shared car journey as planned. Ride-sharing is used in work travel plan by companies as well.

Ride-sourcing is a similar service type as taxi service. But drivers are organized by company and the service car is drivers' personal car. Automated demand-capacity assignment and dynamic tariff system are provided by the telematics system. Registration and reservation are obligatory.

In order to determine the TS-DRT service promotion trends in different cities, I analyzed the mobility system of six cities, examining what kind of transportation mode are available. (Table 1)

Typical cities in Europe (Budapest and Berlin), Asia (Beijing, Hongkong and Tokyo) and America (New York) were chosen, considering the population, area, public transportation utilization and acceptance of new transport service type.

For European cities, such as Budapest and Berlin, the conventional public transportation system developed well, but at the same time, the transport system can relatively easily accept the addition of new components, such as ride-sharing, car-sharing and chauffeur service modes. In Beijing, chauffeur service and ride-sourcing are all operated by the Didi Chuxing company [24]. Especially in high population area, these new transport modes have advantages than taxi service in competition. Shared economy is preferred by Chinese people, Didi Chuxing operated well in Beijing, also in other Chinese big cities. Car2go and Uber works well in New York. But in Hongkong and Tokyo, especially in Tokyo, new transport modes are not very welcomed. Public transportation utilization is relatively high (more than at least 90%), public transportation is the main option for most people both in small area and high population area. In Tokyo, because the government care about the environment and high price of parking are, bicycle is welcomed everywhere, almost everyone has

Table 1. Mobility system of six cities

	Budapest	Berlin	Beijing	Hongkong	New York	Tokyo
population (million)	175.9	347	2150	734.7	853.8	3500
area (km^2)	525.2	891.8	16808	2754	789	622
ride-sharing (intercity)	Oszkar	BlaBlaCar	unknown	Hopsee carpoolworld	unknown	carpoolworld
car-sharing	Avalon Carsharing	Car2go Multicity DriveNow	Togo	Carshare	Car2go	Orix
Taxi	Green taxi Fotaxi	taxicabs	Beijing Taxi	Taxi	Yellow Cab, Oncabs	MK TAXI Hello Tokyo Taxi
chauffeur service	my Driver	BLACKLANE	Didi Chuxing	AVIS	PRECISION	YUYUBIN
ride-sourcing	✖	Uber	Didi Chuxing Uber	Hopsee	Uber	Uber
bike-sharing	MOL BuBi	Call a Bike Next Bike	Mobike Ofo bicycle	Gobee	Citi bike	COGOO baybike COGICOGI
motor cycle sharing	✖	eMio COUP	✖	✖	✖	✖
conventional public transportation	metro, tram, suburban railway, boat, trolleybus, bus	rail, tram S-Bahn U-Bahn ferry, bus	rail subway trolleybus bus	MTR(railway) subway, tram, ferry, bus	rail NYCS(subway) tram ferry, bus	JR(rail) subway tram bus

their own bicycle, the utilization of public bike-sharing system is low as well.

In order to promote service of autonomous vehicles for last mile using in a new mobility system, Budapest, Berlin, Beijing and New York, such cities are more suitable for testing and promotion. Especially European cities with small area and developed economy, which are open to accept the new transport modes. For Hongkong and Tokyo, the automated public transportation maybe much more welcomed than TS-DRT in case of large volume passengers transit can be serviced by the former. Furthermore, the MaaS4EU (Mobility-as-a-Service for European Union) project [19] for nowadays transport system in Europe is already launched, four European cities are as tested cities, included Budapest.

The mobility system based on AVs provided in this research do not simply mean using autonomous vehicles to replace the traditional vehicles in MaaS, as the information management and operation features are different. MaaS4EU project for conventional mobility system is already carried out, its success at least can give a possibility or probability for future solutions. For service testing of TS-DRT, tested cities should be in European, as they are relatively smaller, richer and easily to accept new modes in mobility system.

3.2 Service types based on autonomous vehicles

As Mobility-as-a-Service has the potential to eradicate dependence on private vehicles [19], at this level, MaaS based on AVs is supposed to cover all types of services. In paper [17], author provide two typical forms of TS-DRT: small sized (with 2-6 passengers) Personal Rapid Transit (PRT) and medium sized (with 7-12 passengers) Group Rapid Transit (GRT). Based on that I determined more detailed service types based on AVs in MaaS. The types are illustrated according to flexibility and number of passengers in Fig.4. Table 2 describes the types in detail.

- Special Demand Responsive Transit (SDRT)
- Group Rapid Transit (GRT)
- Small Group Rapid Transit (SGRT)
- Personal Rapid Transit (PRT)

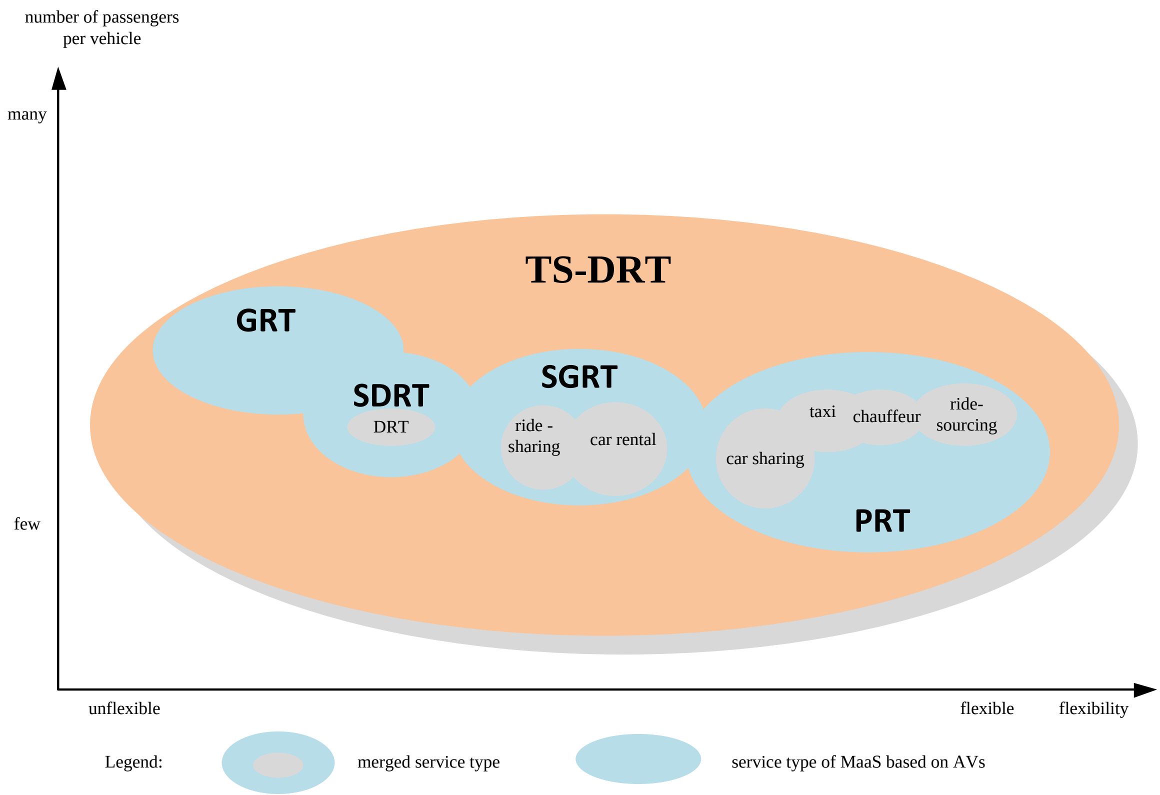

Fig. 4. Service types in MaaS based on AVs

Table 2. Detailed description of service types

service type	full name	capacity	sharing option	reservation	route	timetable	other description
PRT	Personal Rapid Transit	mini, pod exactly for 1 passenger	✗	√	flexible	✗	point-to-point service, separated space, high comfortable level.
SGRT	Small Group Rapid Transist	small, 2-6 passengers	depend on the different situation. For car rental using, no sharing option. For ride-sharing using, has sharing option.	√	flexible	✗	point-to-point service, depend on the different situation, can be used as car-rental service or small group ride-sharing service.
GRT	Group Rapid Transit	medium, 7-12 passengers	✗	✗	fix	√	feeder service to the arterial conventional public transport lines.
SDRT	Special Demand Responsive Transit	small, 2-6 passengers	√	√	flexible	✗	special feeder service to the conventional public transport service for people with disabilities, point-to-point service.

PRT, the mini pod service can satisfy travel demand exactly for one person. For example, this service is appropriate for business people who care for time and prefer separated working space during journey. It is sure for elder people to have seat and comfortable journey. 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 personal space. Etc.

SGRT service can be used if the travel demand is higher (e.g. family, tourists). Service of ride-sharing means small group (less than 6 passengers) travel in the same vehicle during one journey and shared the cost. Depending on the small size of the vehicle, separated personal area is larger and comfortable level is higher. Tourists may prefer this type, AV take them directly to the tourist attractions according to their personalized journey planning and they can share the journey cost with strangers. SGRT Service of car rental means a vehicle rented by one person, no sharing with strangers. For instance, one family member can rent a medium AV for family trip during weekends.

GRT is time-table and fixed route based service, for medium passenger volume (7-12 passengers) transit. Considering service quality, passengers are not allowed to stand on the vehicles, 12 seats exactly for 12 passengers. For example, GRT can be used as school bus and work travel plan vehicles.

In case of shared service type, although SGRT and GRT service can provide separated space (e.g. wheelchair space) for people with disabilities, the totally separated service, SDRT, which is only for people with disabilities, is surely essential. Considering various factors (especially psychological factors), SDRT service type will be provided. Those AVs serviced for SDRT are equipped with extra device, such as ramp for wheelchair which can stretch out and draw back automatically, voice-based guide system for blind people boarding, voice-based or eye tracking device for individuals who do not have arms to enter the vehicle, etc. People with disabilities can apply for a human staff help as well.

“Citizens will not give up private automobiles unless they are offered a service that provides equal sense of convenience, reliability and flexibility” [19]. For private AV using, people prefer its flexibility, but they need to care about charging, maintenance, and parking space, besides, vehicles are idle during the night in the home. AVs in MaaS are managed by transport operators, users do not need to care about the maintenance of vehicles. In addition, when MaaS based on AVs developed into a high level, the well-planned dispatching network of vehicles which is based on reservation, transport network condition, real-time and historical data, the empty AVs and idle AVs will less, even no parking requirement. But considering the high cost of autonomous service, the private autonomous vehicles appear first for richer people, and when the entire transportation system develop into a high level, the service of AVs may replace the individual autonomous vehicles.

Considering the new mobility services should be designed for the real needs of all people, guaranteeing inclusion of the young, the old and people with disabilities, four service type of AVs are provided in MaaS. PRT, SGRT, GRT service can serviced for all people (care for the young and the old), people with disabilities are guaranteed by SDRT service.

4. System structure model of MaaS based on AVs

Mobility-as-a-Service describes a class of applications where conventional real-time control systems are enhanced by backbone services accessed via the mobile Internet [12].

The constituents and their connections of MaaS based on AVs are represented in Fig. 5, system engineering principles are applied to envisage the system during the modelling, and the main components are showed in the system structure model.

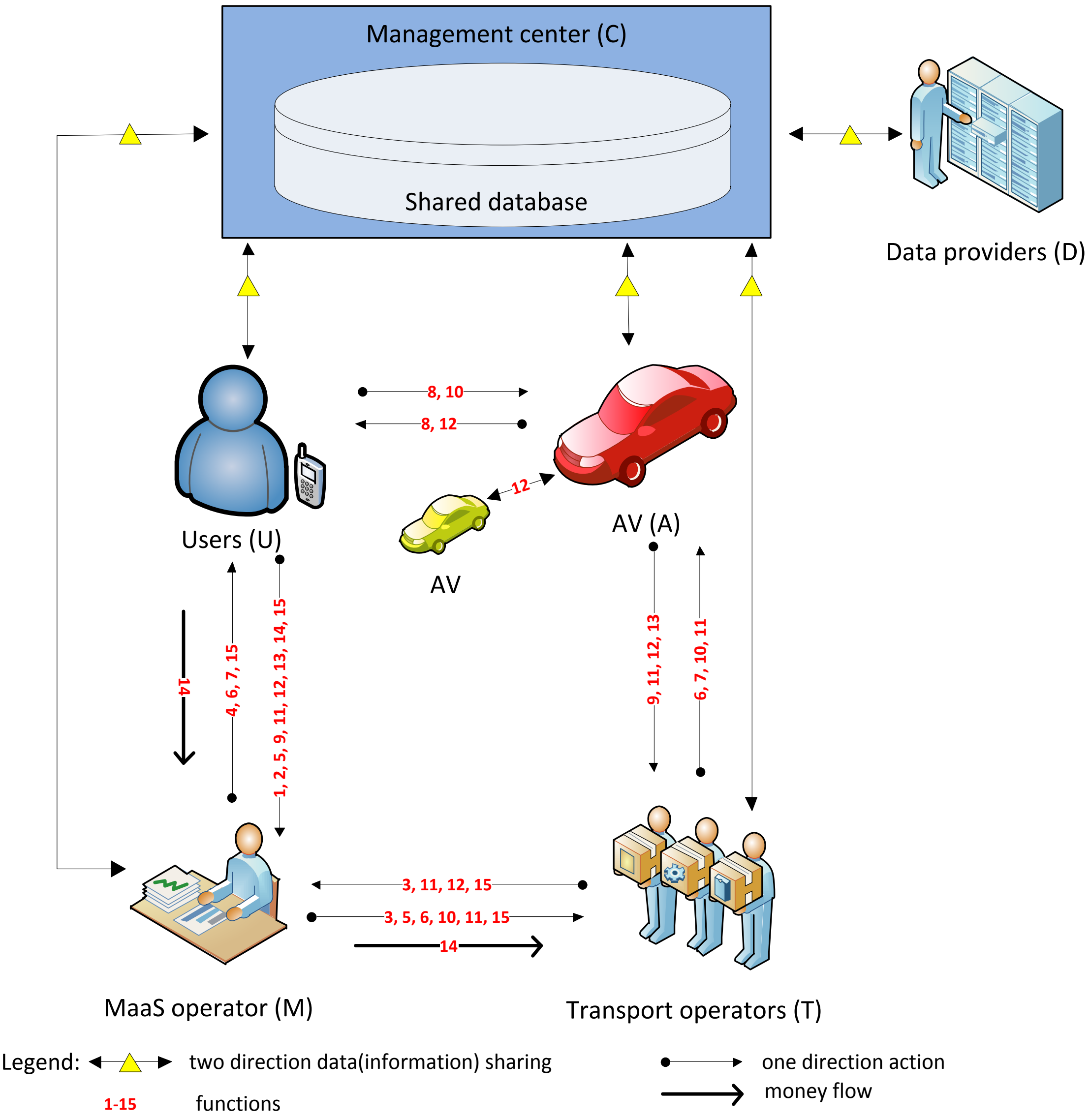

Fig. 5. System structure model of MaaS based on AVs

The connections are represented by arrows, the relevant functions in one related process are represented by numbers (the description of the functions are presented in Section 5.1). One number may be marked on several arrows, if more than two components participate in one function.

The main components are:

U: Users [with smartphone]

M: MaaS operator

T: Transport operators

A: AVs [autonomous vehicles]

D: Data providers

C: Management center [with a shared database]

Users (U) together with smart phones are as 'smart' passengers part in the mobility system. Registration is mandatory, users' profiles and their preferences setting can provide opportunity for MaaS operators to plan personalized route options. Reservation is obligatory, autonomous vehicles are mostly used for last miles, reservation in advance can reduce empty vehicles through task arrangement. Smart phone is also important in the ticketing and payment process. After reservation, user is supposed to get a digital ticket from application and use it during the whole journey (for example, scanning the QR code), and the final payment also by the smartphone transfer.

MaaS Operator (M) act as an intermediary between transport operators and users, by booking (or buying) capacity from the former and selling it to the latter. It also acts as money transfer intermediary who will receive payments from the users and split these payments and transfer to respective transport operators [19]. The multimodal journey planner mobile application can be provided by MaaS operator, which is an important part in the mobility system. For users, booking (reservation), ticketing and payment process are realized by this application, MaaS operator use it to provide the personalized journey route planning.

Transport operators (T) are mobility service providers. Mainly are automated conventional transport operators (automated bus, tram, metro, etc.) for large volume passengers transit, autonomous vehicles service operators, railway service operators and even airline service operators. Aim to make cooperation among those operators, all those services can be ordered through a single interface and user can use one digital ticket to finish their multimodal journey. In my research part, I mainly focus on the autonomous vehicles service operator, this operator responsible for capacity checking and dispatch (sending information) the AVs.

AVs (A) are the main mobility tools in my research part. On the demand side, they connect users and MaaS operator, on the supply side, they connect MaaS operator and transport operator. MaaS based on AVs is an intelligent transport system, so the communication among vehicles (V2V, vehicle-to-vehicle) [3] [9] and vehicle to infrastructure (V2I) are more important. All the vehicles are in an information network, concept of Internet of Vehicles [10] (from Internet of Things) describe such a developed vehicle environment. Information exchange among vehicles and amount of sensors using provide safer driving conditions.

Data providers (D) offer data and information sharing requirements (data privacy and secure data access) for the system operation [19] [20], they are map service providers, weather information providers, traffic control operators, telecommunication operators, technical backend providers, users (users share information among users, social media, etc.), and so on.

Management center (M) is an integrated information management center, it is the head of other centers (MaaS operator center, Transport operator center, Data provider center and Traffic control center). It has huge shared databases to store all the service data, Management center use databases to store, process and classify all type of data and provide Cloud storage service.

a) Stored data resource: as databases in Management center connected with each system components (U, M, T and D), all data from the mobility system have a 'copy' (backup) here, it has large amount of historical data (static data).

- Data of user information model, which capture all data related to the user's profile including MaaS account information, preferences, characteristics and mobility traces. [19]
- Operational data of MaaS operator and Transport operators (included each service process recording.)
- Data from data providers. Dynamic data offered by Data providers can be used only one time, after being used, those data are still precious resource and are stored in this cloud storage as historic data resource. Processed and classified data can be offered to data providers again as well, in this case, not only information sharing between Data providers and Management center, but also a kind of service exchange and technical support.
- Digital cash flow data, data recording of the payment and payment sharing (transfer) processes among Users, MaaS operator and Transport operators.
- persistent transport data such as timetables and historic traffic data

b) Cloud storage: backup all the data, the third-party data backup. After processing and classifying, those collected data can be used for data-as-a-service (DaaS). (e.g. historical data can be used for estimation of travel cost and time). The Cloud storage which are based on Cloud computing technology is the backbone of sharing information. The information sharing process is synchronous, faster, easier and more accurate, without time and place limitation. It is cheaper than the traditional hardware storage as well.

c) Key support for journey route planner (MaaS center): big data is the resource of personalized recommendation services. More related historical data, more appropriate personalized journey route planning. Deep learning can 'learn' from big data, as the key technology of artificial intelligence (AI), the basic resource is the mass data, which are supposed to be provided by this Cloud storage.

In MaaS, users buy mobility services through the MaaS operator, which is not like before directly buying service from different transport operators. In thesis [18], author provides four envisaged service scenarios in a conventional MaaS. In my research, the simplified service process is stated as following.

After obligatory registration with personal information and preferences setting, users can start to use tailored personalized multimodal journey planning services. Once user send the planning request through mobile phone application, the system will process this request at once.

(Booking and ticketing) MaaS operator generates several possible route options according to many aspects (e.g. the weather information, user traveling habitat, user historical travel traces, historical and dynamic traffic data, etc.), then the MaaS operator and relevant transport operators check capacities of selected vehicles, MaaS operator "communicates" (information exchange) with transport operators to make sure the capacity checking process. After that, MaaS operator provides several journey options for users to choose. Once the user sends the confirmed choice for a specific journey, the MaaS operator configurate the journey assignment and transport operators arrange for the separated tasks. A digital ticket (with QR code) and related arrangement information (e.g. vehicle plate number, aboarding position and time, etc.) will send to the users as well.

The user can experience the seamless mobility (multimodal journey) during the specific journey. Especially during the AVs part, they can easily find the ordered vehicles (with real-time information provided by smart phone application). After using the relevant technology to find and enter the vehicle, they will enjoy the driverless vehicle journey. They can use the entertainment device on the vehicles or working during journey.

(Payment) The user can easily pay for their journey with mobile application all in once to MaaS operator, who is responsible for payment sharing (transfer) to specific transport operator. In addition, users are supposed to give feedback through smart phone application, which provide possibility both for MaaS operator and transport operators to improve service quality.

The envisage process is just a small part of MaaS based on AVs. The mobility service can also be among different cities and different countries. The quality of mobility will be much more improved when the MaaS concept is realized. Through a single application, the user can buy all kinds of mobility service (e.g. flight, train, metro/subway, tram/light rail, bus, AVs service, bike-sharing, ferry, cable car, etc.) and they can experience a seamless (multimodal) journey. Even in those complicated cases, users are still just supposed to pay for the final total price, the MaaS operator is responsible for the payment sharing/ transfer.

In this section, the system structure model of Mobility-as-a-Service based on autonomous vehicles was investigated, detailed description of main components (Users, MaaS operator, Transport operators, Data providers and Management center) are presented, a simplified service process was provided as well.

5. System operation for MaaS based on AVs

As my research mainly focused on the information management process of the MaaS based on AVs, the system operational model, data model and dynamic price model which are all related with information management process are presented in detail, to investigate the operation processes of MaaS based on AVs.

5.1 Operational model

In order to operate such mobility system which is based on autonomous vehicles, the following functions are proposed. The operation process is mainly divided into four parts: before journey, journey planning, during journey and after journey. Each part has their own main functions, which are presented as following. The operational model was provided in Fig. 8.

1. **registration.** Real-name registration and user bank account (credit card) providing is obligatory, in order to decrease certain crime (e.g. decrease transactions of ticket scalpers). Personal preferences and individual characteristics setting support to form user's profile. Individual mobility traces and system feedback as well as user's profile support to form the user individual information model. Detailed statistics analysis about the user information model makes the system provide more detailed personalized multimodal journey route planning.

2. **journey planning request.** User send his/her personal journey request, such as from where to where, departure time and arrival time. MaaS operator will process this request.

3. **demand-capacity checking.** MaaS operator dose not buy all the capacity from the transport operators, MaaS operator check first if there is using space 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, real-time information of vehicles is checked as well.

4. **options providing.** MaaS operator provides several options using personalized multimodal journey planner. At the same time, estimated journey time and cost will also be provided respectively based on the historic data. Provided options are all available, they are combinations of different transport modes, the combination order depends on the user preferences and travel habits.

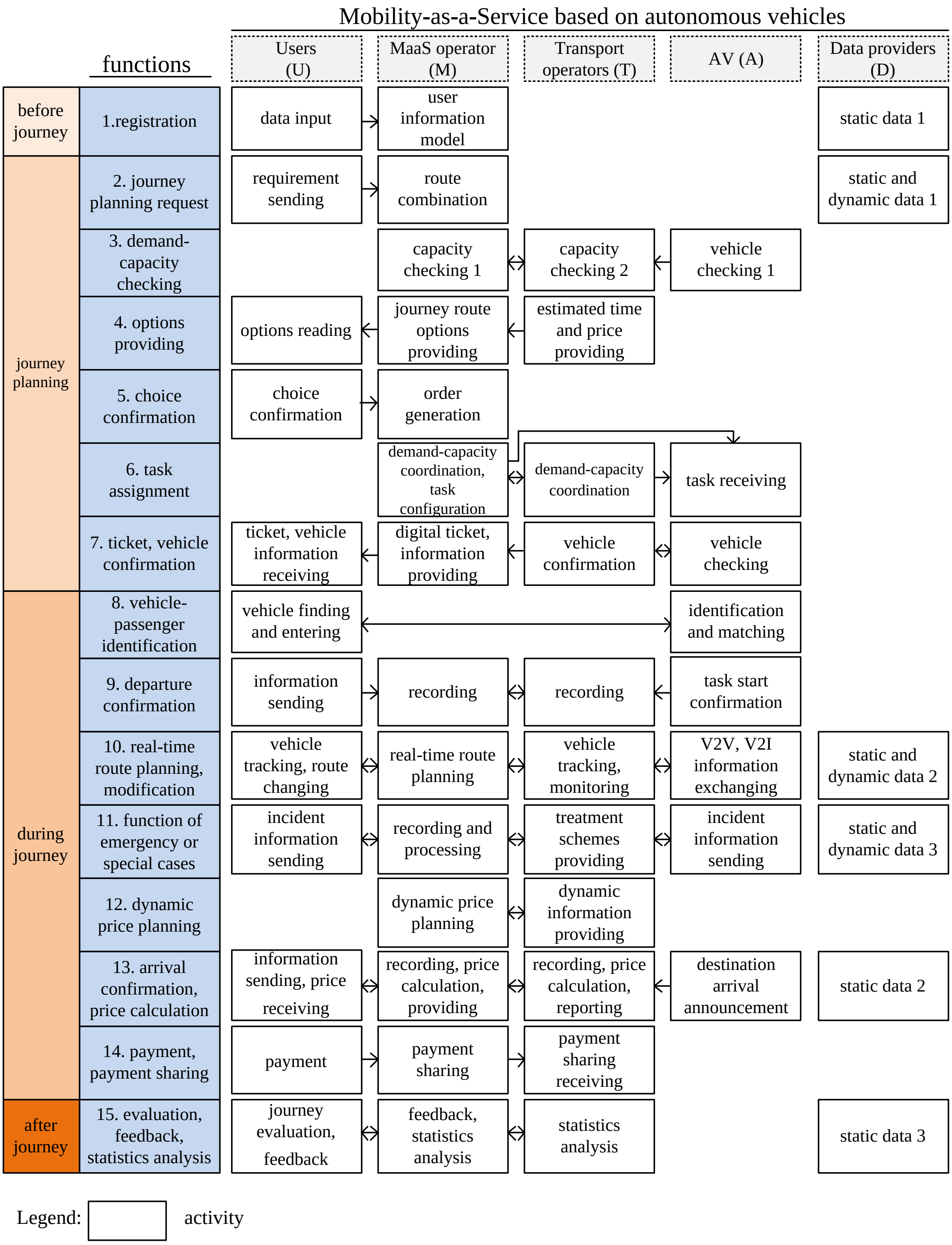

Fig. 6. Operational model of MaaS based on AVs

5. **choice confirmation.** User confirm his/her specific choice, to make sure that MaaS operator can start to coordinate capacity and record this assignment.

6. **task assignment.** If the capacity which MaaS operator bought is enough, just MaaS operator coordinates the demand-capacity, if not, relevant transport operator coordinates it. Maas operator and transport operators confirm with each other and release the booking (change the relevant data). MaaS operator make sure the availability of each part of the journey. And the result of task configuration should notice both the users and the transport operators, the user gets as the vehicle brand, plate number, estimated arrival time and position.

7. **ticketing, vehicle confirmation.** After task configuration part finishing, MaaS operator will send a tailored digital ticket to the smart phone of user, this is a certification of purchasing the relevant specific service. The user can use this ticket during all his/her journey. MaaS can provide two kinds of tickets, pay-as-you-go for all the transport modes needed for a trip or monthly mobility plans, including different amounts of transport services based on their needs. The ticket for pay-as-you-go is for one journey, the digital ticket expires along with the end of one journey. The monthly ticket can be updated every day in order to help the users count the available using days.

   Specific transport operator assigns the task. For example, check AV and dispatch AV (send information) to wait at the right place. The checking process is necessary, to make sure the battery capacity is enough to finish the task. And the service environment is comfortable for users (e.g. air-condition works well or not, entertainment device works or not, etc.), to make sure the average service quality.

8. **vehicle-passenger identification.** Application will help users to find the ordered vehicle. A possible way is using Bluetooth matching technique to match user and vehicle. (smart phone and vehicle can connect, to provide a real-time map for user to find the vehicle). Use automatic fingerprint identification technology or QR code scanning identification technology to open the door of the vehicle. The principle of the identification process is that it will be quick and trustworthy.

9. departure confirmation. A vehicle-passenger assignment announcement process. Both user (passenger) and vehicle send the task starting information to the center. MaaS operator receives the user's information and send to the management center (shares in the shared database), specific transport operator receives the information from the vehicle and do the same task (to make sure the task starting time). Dynamic price calculation process starts.

10. real-time route planning, modification. Because of the altering traffic situation, the route should be re-planned constantly. Besides, vehicle is tracked and monitored during the journey, to make sure of the journey safety. For AVs, V2V and V2I information exchange during the whole journey.

11. function of emergency or special cases. Extreme situation always has probability to happen. For instance:

Collision of AVs: machine-controlled vehicle is safe in most cases, but if unfortunate two AV collide with each other, the primary treatment is always to protect the users. AV has automatic emergency alarm device to send information to the police and management center, to let the relevant operator react to the emergency and deal with it.

Smoking of users: smoking is forbidden when users are in the vehicles. If someone breaks the rule, the sensor on the vehicle will start work and send information to the MaaS operator, the credit score of specific user will decrease at once, furthermore, this user was supposed to be punished to pay extra money—because he/she destroys the inside environment of vehicles.

12. dynamic pricing planning. Data regarding to the real-time traffic and sharing options are collected and coordinated.

13. arrival confirmation, price calculation. Similar procedure and aim as departure announcement. Real service time is calculated by these two times of user-vehicle announcement. Price is calculated considering many factors (e.g. number of remained seats, peak time factor, etc.)

14. payment and payment sharing (transfer). Users directly pay via the smartphone application, MaaS operator responsible for sharing (transfer) the payment to the specific transport operator.

15. evaluation, feedback, statistics analysis. The last but not the least procedure, users' pertinent evaluation and sincere feedback is important for MaaS operator to improve the service quality. For this goal, evaluation and feedback procedure of users are obligatory. Both MaaS operator and transport operators handle with statistics analysis, in order to provide better service.

Management center is not presented in this operational model, as it manages different operator centers.

Data providers do not connect with other components, they provide different data for different using groups during a same function. For example, for the options providing function, relevant data provider should provide real-time traffic data for transport operators to check the possibility of service providing, another data provider need to provide real-time and estimated weather information data for MaaS operator to provide appropriate journey route options. Data providers provide different data for different target groups. Fig. 7 is used to explain how the data providers provide information during all the journey.

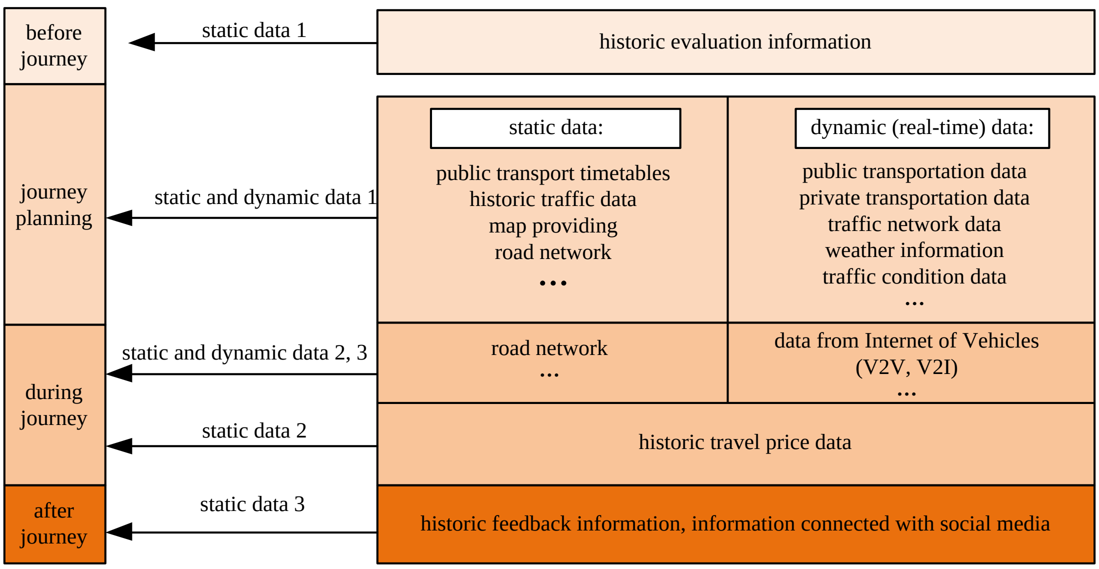

Fig. 7. Data providers

The detailed planning procedure was illustrated by Fig. 8.

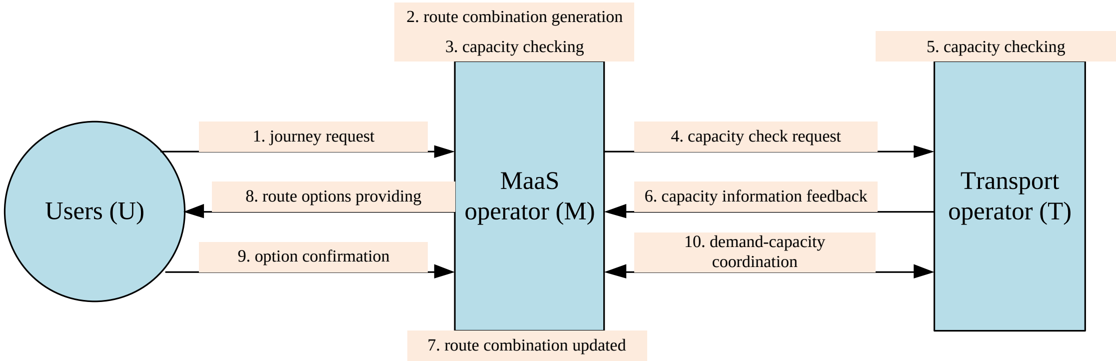

Fig. 8. Capacity checking process

- In case of MaaS operator has enough capacity, the planning process is: 1, 2, 3, 7, 8, 9, 10.
- In case of MaaS operator do not have enough capacity, all the processes are necessary.

Route options providing is the key task of multimodal journey route planner (part of MaaS operator), which provide personalized planned route options for users. Route options are not only the combination of different transport modes, but also considering users' preferences and travel habits. Personalized mobility service is addressed in the planning procedure. Multimodal route planner not only plan route options for users, but also provide recommendations, the best transport modes combination (in this level, both private and public transport modes should be considered, it means an integrated database which contains both private and public transport service information is required) and fast journey route (may not the shortest route, but travel time spending is shortest) options, the order of the provided route options is the recommendation ranking.

In this section, operational model for MaaS based on AVs was presented, detailed information management processes (functions) were provided, furthermore, route options providing as a new function of multimodal journey route planner (key part of MaaS operator) is investigated in detail.

5.2 Data model

During entire information management processes, as data keep the system components together, I identified the attributes of each entities (except data providers and management center) and elaborated the relational database structure of the mobility system. The tables (entities) without attributes and their connections illustrated by arrows are presented as simplified data structure (Fig. 9). This data model is an operational model for service of AVs.

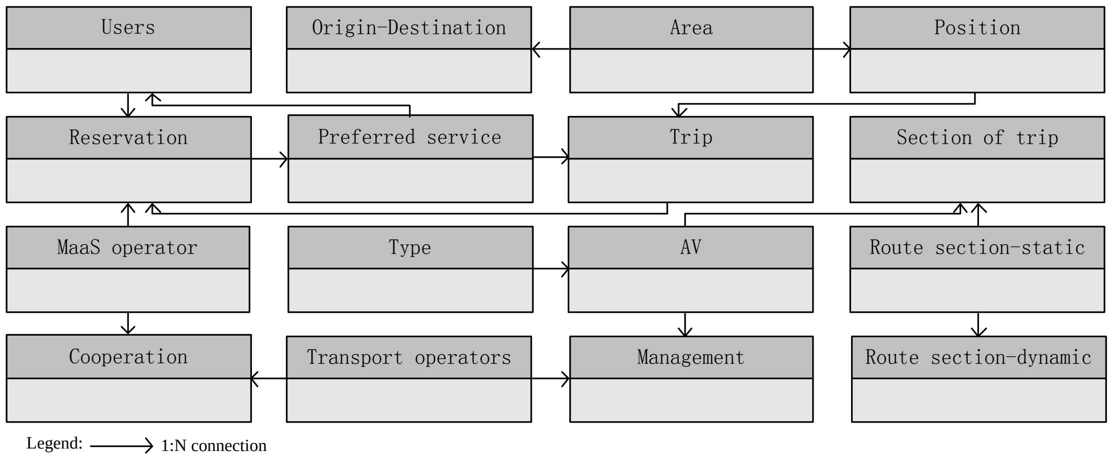

Fig. 9. Simplified data structure

Data providers do not have direct connection with other components, so it is not presented in this data model.

In my research, as I focus on the service of AVs part, transport operators of automated big bus, tram, metro, etc. are not considered. Reservation for those service (together with GRT service) are unnecessary, but when journey planner provides route options, those transport modes are also included. User use the same digital ticket to access the conventional transport parts and pay for them together with the AVs service parts.

General data of users are stored in Users table, those data include users' profiles and users' preferences (e.g. user name, credit card number, preferred seat location, discount type, etc.). Each user must register in. Preferred service type table connect with users table which simply store the service type (e.g. PRT, SGRT, GRT, SDRT, bus, metro, etc.), for operational purpose, MaaS operator can search for preferred service type of potential users. Reservation table contains information of each reservation (e.g. selected seat location of the vehicle, estimated trip time and price, etc.).

Trip table contains information of the trip (e.g. departure and arrival time, walking distance, trip price, etc.). Position table contains data of each position (AV arrival and departure point), longitude and latitude data are recorded to identify this position. Area table contains the area type (suburban area or urban area). Origin-Destination table is for identifying the trip area (suburban trip or urban trip or between them). Section of Route table is a connect table. Route-static table contains the static information of a trip (e.g. starting and ending position of route, length of route, etc.). Route-dynamic table contains data about conditions of route which should be considered in the route planning and in the dynamic pricing (e.g. weather, peak time factor, time period factor, etc.).

The AV table contains static data (e.g. plate number, the number of seats, color, etc) about the vehicles. Transport operator manage AVs. Type table contains the service type of vehicles (PRT, SGRT, GRT and SDRT), passenger and battery capacity, basic price of service, etc. AV-dynamic table are mainly used for counting the number of remaining seats of vehicle (remaining capacity influence demand, supply and dynamic pricing). Management table is a concept table, it contains the information of dispatched AVs, for instance, the checking information (charging, maintenance, etc.).

Transport operators table contains different transport operators, operator of GRT is different from SGRT and PRT, former do not need reservation but still need to be dispatched by GRT operator. Cooperation table contain information among transport operators and MaaS operators (for capacity checking). Each capacity checking is recorded in this table with communication ID. As MaaS operator responsible for payment sharing, MaaS bank account is stored in MaaS operator table.

The detailed data structure with attributes were elaborated in the Microsoft Access software (Fig. 10), where the primary and foreign keys are also presented.

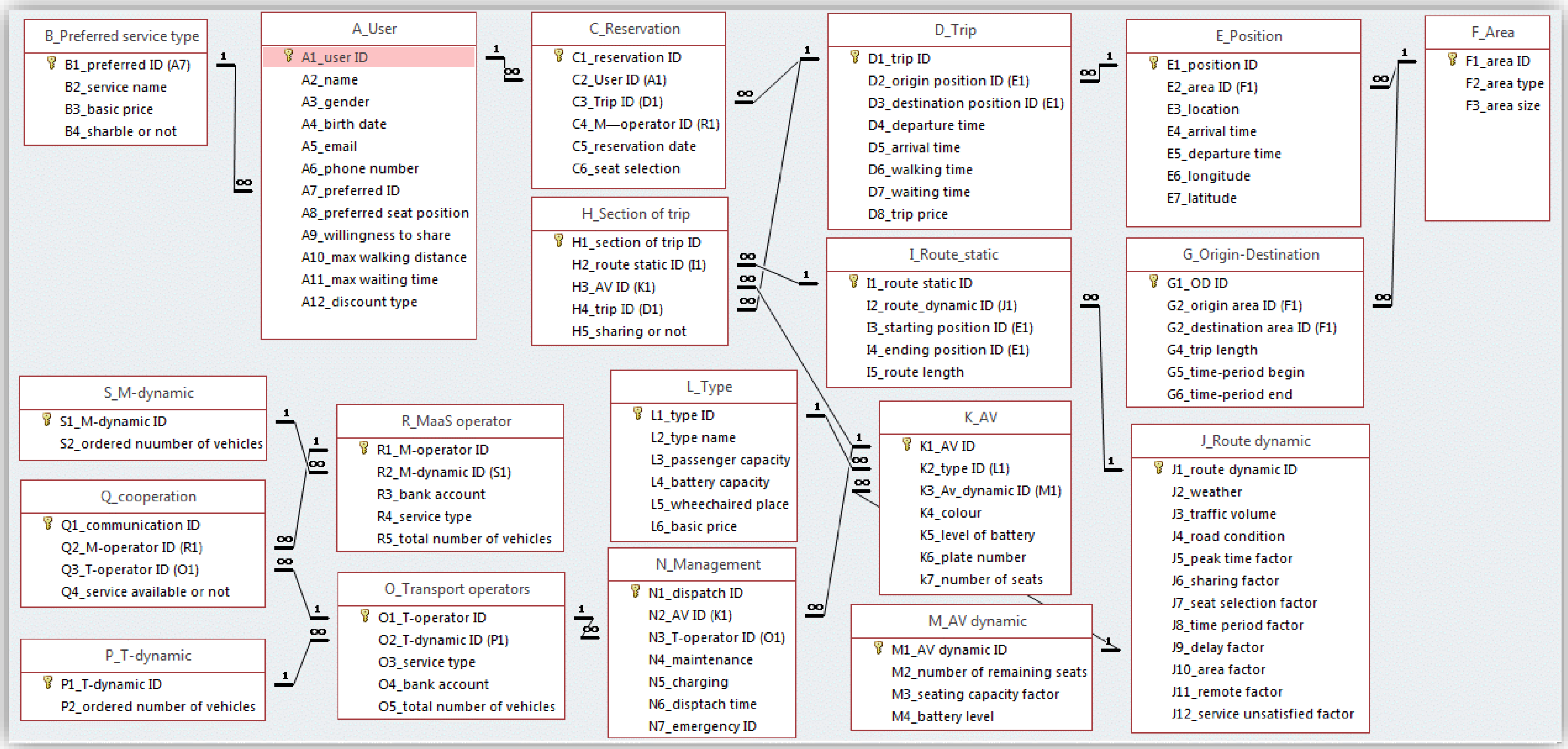

Fig. 10. Detailed database structure

Electronic cash flow is special information management process, especially in the MaaS. Users do not directly pay to the transport operator, in verse, they pay to the MaaS operator, MaaS operator is responsible for payment sharing (transfer). This information management process was also presented with simplified data structure (Fig. 11)

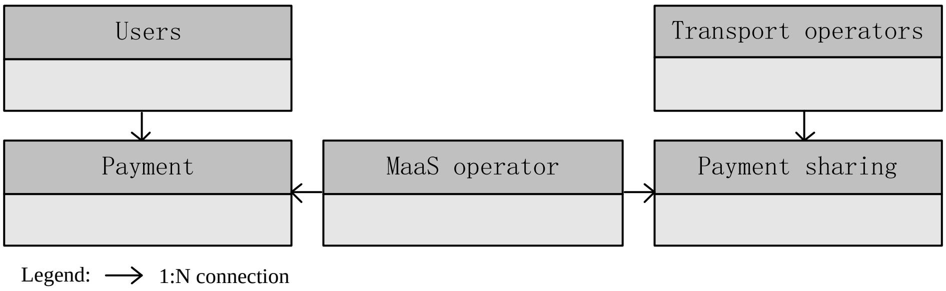

Fig. 11. Simplified data structure

The detailed data structure with attributes were elaborated as well (Fig. 12).

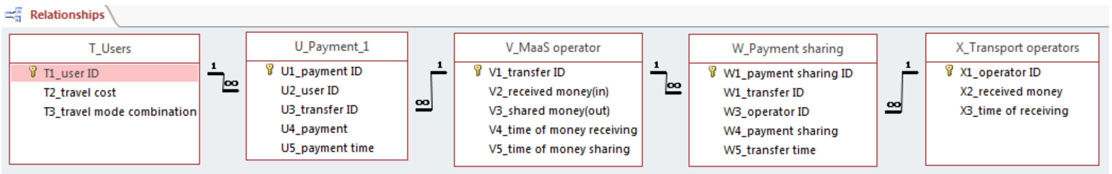

Fig. 12. Data structure of electronic cash flow

In this section, data model for operation service of AVs and for electronic cash flow are elaborated. Simplified database structure shows the connection of main components, detailed database with attributes describe the service operation processes. Each table in operation data modeling was presented in detail.

5.3 Dynamic pricing model

As price can influence demand and supply, dynamic pricing as an important information management function was investigated and presented with dynamic pricing model, service promotion part was carried out for identifying MaaS market.

6.3.1 Dynamic pricing model

A dynamic tariff system was supposed to provide for Mobility-as-a Service based on autonomous vehicles. Service price can affect demand and supply side, in verse, demand and supply side can also affect service price. Like air service, the service price will change along with the number of remaining seats. The sooner reservation, the lower price (MaaS operator and AV service operator have enough time to optimize tasks). As a rapid transit service, except for the number of remaining seats, there are other factors which also affect the dynamic pricing, I determined the main factors in Table 3.

Set of values were provided as percentage interval (the value of most factor is between 0% to 200%), according to experience and website material (e.g. taxi service, Avalon car sharing company in Budapest, etc.).

- Sharing factor: in case of shared autonomous vehicles (SAVs), the service fee is lower, because passengers who journeyed together shared the journey cost, in my case, SGRT and GRT service is mainly for shared service, and this kind of service is preferred in the future for its saving-resource aspects.
- Area factor: autonomous service for last mile using will be also provided in the suburban area (compared the urban area, the amount is low), but in this case the basic service fee is higher than in urban area (demand is low, in order to balance operation cost, average basic service fee is higher compared with the urban area).
- Remote factor: flag-down fare within 15 km is lower in case of taxi service, service fee per km is little higher over 15 km part (most taxi service charge for extra money after 15 km). Service of autonomous vehicles is mainly for last mile

Table 3. Parameters in dynamic pricing

Category	Sign	Term	Sign	Set of values	Explanation
Demand and supply	F_1	seating capacity factor	F_1	0% ~ 200%	Price is affected by number of remaining seats
Flexibility	F_2	sharing factor	F_2	0% ~ 100%	shared vehicle or not
Spatiality	F_3	area factor	F_{31}	100% ~ 200% (suburban area), 100% (urban area)	suburban area or urban area
		remote factor	F_{32}	100%~200%	distance between origin and destination is remote or not (mainly for last mile using)
Temporality	F_4	period factor	F_{41}	100% (day), 20% ~ 30% (night)	day or night
		peak time factor	F_{42}	100% - 200%	peak time or not
		delay factor	F_{43}	0% ~ 100%	delay or not (punctuality)
Discount	F_5	frequent factor	F_{51}	0% ~ 100%	discount for frequent user
		elder factor	F_{52}		discount for elder people
		student factor	F_{53}		discount for students
		disabled factor	F_{54}		discount for disabled people
Quality	F_6	seat-selection factor	F_{61}	100% ~ 200%	space (seat selection or not)
		Service unsatisfied factor	F_{62}	50% ~ 100%	vehicle was not clean, the waiting stop was not clean (GRT service), the smell in the vehicle was not good, air-condition did not work, entertainment device did not work, etc.

- using, in the remote distance case (for operation purpose, MaaS operator decide the remote distance), many other aspects should be in consideration, such as charging requirement. The remote factor is necessary for dynamic pricing.
- Period factor: overall, service price during the day will be higher than during the evening. The car sharing company Avalon [25] in Budapest provides such calculation solution: service price during the day (from 6:00-22:00) is higher than the night (from 22:00-6:00). In my case, time period factor is also considered as a price affected factor.
- Peak time factor: peak time or peak hour is most important factor which mainly affect the dynamic pricing. Historical data can estimate peak time. For daily commuting, peak time is faced by everyone. Peak hour is around 6 am to 9 am in the morning, and 4 pm to 7pm. Demand exceeds supply, higher service fee is reasonable (even during the reservation, the estimated journey cost covers the peak hour factor). Avalon, Uber, etc. such car-sharing or ride-sourcing company already can provide the estimated journey cost for users, but the estimated cost is not accurate, in most cases, final price changed a lot. In the dynamic pricing system of autonomous vehicles, more accurate estimated service price is offered considering all kinds of factors.
- Delay factor: the service punctuality is explained in a time axis: (Fig. 13)

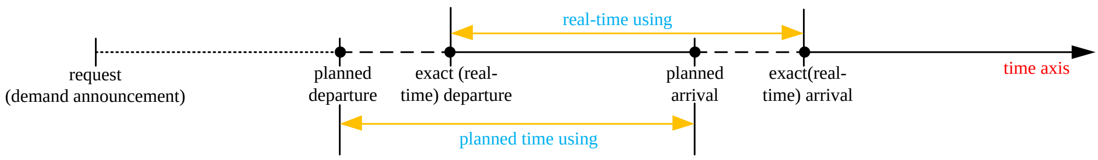

Fig. 13. Time axis of punctuality

The difference will be smaller and smaller between real-time using and planned time using when the vehicle delays shorter time, real-time using equals to planned time using means the vehicle is absolutely punctuality. Relatively, delay time is acceptable if it is less than X minutes (e.g. 10 minutes, for operation purpose, acceptable delay time is decided by the MaaS operator), if more than X minutes, it means vehicle delay and delay factor is offered to decrease the journey cost.

- Discount factor: four main discount groups are in consideration: frequent users (using service time is more than Y times per month, for operation purpose, Y is decided by the MaaS operator), elder people (care for the old), students (care for the young) and people with disabilities. One user can only take one discount category (generally take the maximal one), no multiple discounts.
- Seat selection factor: high quality mobility services are offered by autonomous vehicles, at this level, it is important to provide seat or separated space for every passenger. Seat near window, seat with table and seat with separated space are charged for different price, in order to provide users-centered service. e.g. for SGRT service, users can choose their seat place: near window, near door, working-table space, or even separated space for one people using (recommend for business travellers or commuters, they do not need the entertainment activities to kill time like the tourists, to the contrary, they prefer separated space to relax themselves or they can work during the journey).
- Service unsatisfied factor: offer opportunity to feedback unsatisfied service experience, in such cases, journey cost will decrease considering the service unsatisfied factor.

Considering the above factors and real travel distance (d), the basic service price (m_0, three different basic service prices represent as $m_{0\text{-PRT}}$, $m_{0\text{-SGRT}}$ and $m_{0\text{-GRT}}$.), a dynamic price calculation method was provided:

$$\text{price} = \text{conventional PuT part} + \text{ AV part}$$

Price for each AV part was calculated and then summed up:

$$\text{price} = \text{conventional PuT part} + \sum \left(m_0 \cdot \mathrm{d} \cdot \prod F_{ki} \right),$$

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

Parameters (all the factors and m_0) and variable (d) in this formula are attributes in the provided database, value of them are stored in the database as well. Price of AV part is calculated as following (conventional public transportation part is not presented in data modal):

$$D_8 = \text{PuT part} + \sum L_6 \cdot I_5 \cdot M_3 \cdot J_{6,7,8,9,10,11,12} \cdot A_{12}$$

where $L_6 = m_0, I_5 = \text{d}, M_3 = F_1, J_6 = F_2, J_7 = F_{61}, J_8 = F_{41}, J_9 = F_{43}, J_{10} = F_{31}, J_{11} = F_{32}, J_{12} = F_{62}$, min A_{12} is considered as discount factor.

Table 4 provide information for those factors affect the service type or not, '✔' means affect, '✖' means not affect.

Table 4. factors towards service type

Factors	Sign	Service type			
		PRT	SGRT	GRT	SDRT
basic price	m_0	m_{PRT}	m_{SGRT}	m_{GRT}	m_{SDRT}
seating capacity factor	F_1	✔	✔	✖	✔
sharing factor	F_2	✖	✔	✔	✔
area factor	F_{31}	✔	✔	✖	✔
remote fee	F_{32}	✔	✔	✖	✔
period factor	F_{41}	✔	✔	✖	✔
peak time factor	F_{42}	✔	✔	✖	✔
delay fee	F_{43}	✔	✔	✖	✔
frequent factor	F_{51}	✔	✔	✔	✔
elder factor	F_{52}	✔	✔	✔	✔
student factor	F_{53}	✔	✔	✔	✔
disabled factor	F_{54}	✔	✔	✔	✔
seat-selection fee	F_{61}	✖	✔	✖	✔
service unsatisfied factor	F_{62}	✔	✔	✔	✔

During calculation, '✔'means take the value of factor, '✖'means take the value of 1.

In this section, dynamic pricing model was presented considering various of factors, a simplified price calculation method was provided for price calculation.

5.3.2 Service promotion regarding the dynamic pricing

Service of AVs in Mobility-as-a-Service is step by step process. Advanced reservation is obligatory during the first stage, instant booking will also be provided but with high price, operator prefer pre-booking. The same, at first stage, this mobility service may have target user groups, different service level for different user groups, later the autonomous vehicle service becomes a mobility service for everyone.

1. Market segmentation

1) User group segmentation

$$\text{users}\begin{cases}\text{time} - \text{more sensitive users} \begin{cases}\text{business travellers}\\ \text{commuters}\end{cases}\\ \text{price} - \text{more sensitive users: general travellers (e.g. tourists)}\end{cases}$$

Time-more sensitive users refer to users who care time more than price, they can accept higher price with instant booking when necessary. Price-more sensitive users refer to users who care price more than time, they prefer pre-booking with lower price (e.g. tourists). This roughly classification reflects the attitudes of this two groups of users towards journey cost. In general, time-more sensitive users can accept traffic modes with relatively higher price than general travellers, they have more limitation towards time. In some cases, they have to change their journey plan immediately because of business requirement, instant booking is preferred in such circumstances. In verse, price-more sensitive users care price more, they plan well for their journey and no big changing requirement, they carefully deal with pre-booking service.

2) Service type:

Mainly is divided into two parts:

conventional PuT part + AVs part

$$\text{conventional PuT} + \begin{cases}1)\ PRT\\ 2)\ SGRT\\ 3)\ GRT\\ 4)\ SDRT\end{cases}$$

$$
\begin{cases}
1)\ PRT\ (higher\ basic\ price, first\ class) \\
2)\ SGRT\ (middle\ basic\ price, business\ class) \\
3)\ GRT\ (lower\ basic\ price, economy\ class) \\
4)\ SDRT\ (\ basic\ price\ between\ middle\ and\ low)
\end{cases}
$$

Using 'first class, business class and economy class' those concept from airline company to explain the level of AV service. The price gap is not too much like the flight. But AV service have different level for target user groups, with target user groups, the operator is easier to estimated demand requirement. During period of transition (from conventional motorized vehicles to autonomous vehicles), the price gap is little bigger, but when the AV service fully developed, the price gap will become much smaller.

3) User groups with recommended service type (detailed market segmentation)

The following relative classification is an example.

$$
\text{users}
\begin{cases}
\text{time} - \text{more sensitive users}
\begin{cases}
\text{business travellers}
\begin{cases}
\text{high} - \text{end business traveller} < 1) > \\
\text{ordinary business traveller} < 2) >
\end{cases} \\
\text{commuters}
\begin{cases}
\text{high} - \text{end individual commuter} < 1) > \\
\text{ordinary individual commuter} < 2) \text{ or } 3) > \\
\text{company group commuters} < 3) >
\end{cases}
\end{cases} \\
\text{price} - \text{more sensitive users: ordinary travellers}
\begin{cases}
\text{middle} - \text{end individual traveller} < 2) > \\
\text{low} - \text{end individual traveller} < 3) > \\
\text{group travellers} < 3) >
\end{cases}
\end{cases}
$$

There, SDRT is not discussed. SDRT is special service for people with disabilities.

2. Multiple pricing (tiered pricing)

To determine the basic service price for different AV categories, based on the characteristics of detailed user groups segmentation and recommended service type.

For instance, in case of PRT, the target user groups are high-end business travellers and high-end individual commuters, MaaS operator should do the market survey according to those target user groups in order to set the basic price $m_{0\text{-PRT}}$.

3. Price discrimination (third-degree price discrimination)

$$
\text{basic price}
\begin{cases}
\text{pre} - \text{booking (price is lower, but time is inflexible)} \\
\text{instant booking (price is higher, but time is flexible)}
\end{cases}
$$

The discount for pre-booking can consider the way by airline companies (dynamic price model based on demand and supply). The pre-booking is recommended for travellers, the instant booking with higher price is recommended for business people. This recommendation guide target user groups to use different level of AV services. Although the pre-booking is cheaper, the instant booking is a growing trend. To go on a trip which is decided on a whim is a reward for normal daily life, especially for young generation. In addition, more and more people can afford the instant travel, it means they can choose the instant booking as well. But for MaaS operator and transport operators, they prefer pre-booking, they can coordinate capacity and demand much more better and efficient in pre-booking cases.

In this section, a possible way to segment potential MaaS market regarding dynamic pricing was provided, booking issues in MaaS (pre-booking and instant booking) were also discussed. A segment market with target consumer groups can earn more profits, which is advantages of a new service promotion.

6. Conclusion

Mobility-as-a-Service (MaaS) operator aims at providing an interface to integrate all kinds of transport modes and a platform (smart phone application) for users to plan a multimodal journey and to pay only once for this journey. In the future, autonomous vehicles (AVs) will replace the conventional vehicles in MaaS as well to provide such seamless mobility services. The system structure and information management processes will also be different. During my research, I made detailed literature review and studied engineering methods to investigate the difference between MaaS and Maas based on AVs.

New mobility service types (PRT, SGRT, GRT and SDRT) were provided for the real needs of all people. By applying top-down approach of system engineering principles, a structure model of MaaS based on AVs was provided. A detailed operational model was elaborated to know how this information system works. A data model was also proposed to describe the system operation. As dynamic price influences the transport demand and supply, this main function was elaborated in detail with a dynamic pricing model to calculate the service fees.

The main difficulties encountered during the research:

- Describing the structure and service of a future mobility system on the strength of research materials,
- Exploring the detailed information operation processes and their relationships with simplified figures,

I will make continuous further research in the following directions:

- Conducting a questionnaire survey on attitudes towards the acceptability of services provided by autonomous vehicles in MaaS,
- Including the infrastructure, battery-charging and parking problems in the mobility system analysis.

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