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## Demand-capacity coordination method in autonomous public transportation

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### Abstract

Technology of autonomous vehicles (AVs) is getting mature and some types of autonomous public transportation have been successfully tested. However, the replacement of conventional public transportation requires new planning and operational methods. The research questions were how to designate stops, routes, operational time, travel frequency and how to model the seat reservation process in order to satisfy personal requirements of travelers. As the operation of the new transportation system is to be derived from the user demands it has been investigated and described in detail, which was the base of the demand-capacity coordination method. Both the preliminary capacity planning and the real-time coordination methods have been developed with special focus on the required data structure and the information management processes. The methods are to be applied during creation of this advanced, high quality mobility service.

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### 1. Introduction

Autonomous cars are unmanned (driverless) vehicles that move without human intervention and being equipped with a number of high-tech sub-systems. AVs analyze the current situation on the road and make reliable decisions concerning the vehicles' manoeuvres, such as: lane changing, safely crossing the intersection, overtaking other

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vehicles, pulling over and riding along the planned path (Owczarzaka and Żak, 2015). The largest advantages of unmanned vehicles according to many researchers (Basulto, 2013; Jakubiec, 2014; Szymczak, 2013; Yeomas, 2014) are as follows: improvement of road safety, elimination of restrictions related to age and disability of passengers, possible increase of the road space (if the utilization of AVs is reasonable), reduction of the required parking space in the city centre and environmental friendliness (assuming they are 100% electric vehicles), associated with reduced emission of harmful compounds into the atmosphere. The most frequently mentioned disadvantages of driverless cars are (Basulto, 2013; Yeomas, 2014): lack of legal regulations concerning unmanned vehicles, high risk of failure, high cost of investment. Despite these concerns, the authors claim that the advantages of AVs exceed their disadvantages.

The advancements in modern technology made possible the comprehensive integration of essential systems and data for AVs operation. The most relevant technological results:

- Global Positioning System (GPS) – Satellite-based global location and time reference of objects (vehicles) for accurate and constant position tracking.
- Inertial Navigation System – Monitors and calculates positioning, direction and speed of a vehicle with motion and rotation sensors on-board.
- Laser Illuminated Detection And Ranging (LIDAR) – Laser detection sensors to identify surrounding objects, or terrain, with data for precision measurements of distance to the objects.

The synchronization of these advanced positioning systems collectively provides the decision-making data. These are necessary for an AVs to be aware of its position and movements in relation to the surrounding conditions (Arseneau and Roy, et al. 2015).

An important function of AVs is communication between themselves (V2V - Vehicle-to-Vehicle interaction) and with the infrastructure (V2I - Vehicle-to-Infrastructure interaction). Both ways of communication are possible due to the installation of communication sensors and antenna transceiver in AVs and in the road infrastructure (Basulto, 2013; Yeomas, 2014). These solutions ensure that vehicles can communicate with each other, send warnings about the existing dangers, inform each other about the traffic congestion, etc.

Considering all above mentioned facts it is reasonable to state that public transportation service can be partially based on AVs in the near future. Consequently, it requires and implies introduction of new demand-capacity coordination method considering personal requirements of travelers.

The remainder of the paper is structured as follows. In Section 2, the situation analysis is provided by review of the existing services. The main features of the new demand-capacity coordination method are determined and summarized in Section 3. In Section 4, the information system model of demand-capacity coordination method is presented. The paper is completed by the concluding remarks, including further research directions. This paper does not provide a novel designation method for predefined stops as well as details about fare system and charging process. The objective of the article is to elaborate the principle of the new service based on autonomous minibuses considering certain segments of route.

## 2. State of the art

Two approaches can be used for designation of stops and routes related to autonomous bus transportation:

1. Alex Forrest and Mustafa Konca (2007) suppose that it is enough to change convenient buses to AVs providing that specific routes and stops remain as nowadays. The problems would arise from actions of conventional vehicles as drivers may lose control and cause accidents with AVs. The ideal situation is when the AV systems have matured to the point that nearly every vehicle on the road is autonomously driven. This would allow to avoid accidents on the road.

2. Designing an Automated Demand-Responsive Transportation Service (ADRTS) providing individualized rides without fixed routes or timetables.

Many considered concepts of application of AVs in urban transportation system assume that unmanned cars operate as the type of Public Transportation On Demand (PTOD), which is often called as flexible public transportation. In this system demand for transportation services are coordinated with transportation supply associated with the availability of capacity and the adjustable way of moving vehicles in the transportation network

(Vuchic, 2007). The basic characteristics of PTOD are as follows:

- Replacing regular fixed routes/lines by flexible vehicle routes adjusted to the reported transportation demand (current passengers' needs).
- Elimination of fixed timetables by dispatching vehicles when the need for passengers' transportation is required.
- Using a heterogeneous fleet of vehicles, featured by different sizes/capacities.
- Replacing regular stops by dynamically changing pick up points (reported by passengers).

PTOD can only be used when the demand is relatively low as the road capacity is limited.

The ADRTS is a kind of PTOD system which consists of a fleet of fully automated electric vehicles that is operated on a network with predefined pickup and drop-off locations. Specific basic characteristics of ADRTS are as follows:

- Passengers access (and egress) at predefined pickup and drop-off locations.
- The service runs the shortest path (no detours).
- Vehicles are shared simultaneously.
- Maximum passenger waiting times are guaranteed.

On their arrival at a pickup location, travelers request the service of a vehicle to transport them to their desired drop-off location. They freely choose their departure time and their pickup and drop-off locations within the ADRTS network. Users traveling between the same locations within a certain time window, which is determined by the predefined maximum vehicle dwell time, are transported together. They thus share a ride, which is subject to vehicle capacity constraints. Travelers have to wait for a vehicle to serve them and will experience on-board idle time while they wait for potential passengers with the same travel destination. After users disembark at their destination, the vehicle remains at its position until it is requested for a new service (Winter and Cats, et al. 2016).

This approach, on the one hand, seems to be effective solution; however, on the other hand it has weaknesses. The shuttles filling time at a pickup location is stochastic process and the passenger idle time is unpredictable. However it is obviously that rational using of intermediate stops leads to decreasing of idle time. We propose a novel method called Automated Random Transportation Service (ARTS). ARTS is a new service of pick up passengers at predefined locations according to vehicle -capacity (e.g. X passengers per vehicle according to AVs manufacturers solution).

### 3. Mobility service description

#### 3.1 The concept of the ARTS service

In our proposed method the routes and stops remain predefined as in the case of conventional public transportation service, but movement of shuttles (e.g. minibuses) are be assigned automatically by the Decision Making Server (DMS). DMS is the main element of the automatic information processing system. It belongs to the transport company (operator), consequently, being located, for instance, in the central office of such company. It means that shuttles decide whether to stop at an intermediate stop or not according to the information received about passengers. Since routes are predefined they consist of origin and destination stops which serve for shuttles as kind of terminals with recharging and maintenance functions. In case of proposed study each intermediate stop also contains charging and maintenance points. Movement is implemented in both directions by minimum two shuttles with an average speed 30 km/h. After travelers disembark at the terminal, vehicle starts next trip in the opposite direction requested for a new service. Trip registration is implemented by Special Ticket Vending Devices (TVD), established at each bus stop or through the mobile application. If registered passenger is absent then starting movement time from each stop is 5 or 15 minutes. Variation of time related to rush hours. For instance, if we take under consideration route with 7 km length and average speed 30 km/h, travel time is 14 minute per one direction trip. Consequently 28 minutes are necessary for complete trip in both directions between point A and B. It means that during 1 hour minibus with vehicle-capacity of 10 passengers can make 2 complete trips. Subject to this

condition one AV can transport approximately 40 passengers per hour. If DMS indicate that amount of registered passengers are more than 40 passengers per hour, then waiting time of late passenger is 5 minute. In case when 40 or less, waiting time is 15 minutes. If there are no passengers each vehicle remains at its position. In case of proposed service only emergency stop is assumed in an unplanned location. Every shuttle must contain places for mobility impaired people. This issue is to be considered by AVs production companies.

The main target of this method is to accelerate the filling time of the shuttles through the fact that all passengers have the same destination point, but different origin points. But the shuttles will work on the principle of ‘X first passengers’. Number of passengers all together should be X persons on a route regardless of at which particular stop or how the tickets were purchased (e.g. via mobile app). Thus, vehicle-capacity is the sum of passengers registered earlier than other travelers from different stations where they wait for a minibus, except destination point. The boarding passengers identified by electronic ticket with ID code which is received on the smartphone and scanned on boarding time by special device on board of AV. After passengers disembark at the final point, counter is reset and DMS give a signal to the shuttle that it is empty. For instance, if situation with two intermediate points A1 and B1 between origin A and destination B is considered and DMS gives command to pick up passengers from the origin and stop at both of intermediate stops, then vehicle-capacity can be shown as the following equation:

$$X = a + a_1 + b_1 \quad (1)$$

where  $a$  - number of passengers from origin station (A),  
 $a_1$  - number of passengers from intermediate stop A1,  
 $b_1$  - number of passengers from intermediate stop B1.

The advantage of this method as opposed to ADRTS is that from several different stops it needs less time to collect information about X passengers readiness to trip. And time while requests for the ADRTS will combined in case the passengers share the same pick-up and drop-off locations can achieve maximum value. Table 1 represents comparison of ADRTS with ARTS according to flexibility features.

Table 1. Comparison of ADRTS with ARTS according to flexibility features.

Flexibility features	ADRTS	ARTS
Spatiality – location of boarding and alighting	at designated (conditional) stops or anywhere	at designated stops
Spatiality – bound or unbound routes	partially bound or unbound	on bound routes (lines)
Temporality (schedule)	just the departure time at important stops are fixed or no timetable	no timetable (movement begins as the shuttle is full or after maximum waiting time)
Users	registered persons	registered persons
Pre - ordering	necessary	necessary
Charge/fee	fixed	fixed or dynamic fee

### 3.2 Implementation of the ARTS service

The implementation of the service and the background information system can be achieved by applying the following components:

- Special Ticket Vending Devices (TVD) equipped with display to trace exact position of the shuttle, number of free places, battery level and other different information. TVD provides possibility to preliminary or current seat reservation via paying by card, cash or internet money. Devices are established at each bus stop.
- Mobile application which provide opportunity to reserve free places and pay fare through the internet services. Each passenger can choose any preferred free place.
- DMS (Decision making server) which sends information to the shuttles that all seats are potentially full. Consequently, it gives the command to start picking up of passengers and move to the next bus stops avoiding unnecessary stops where passengers were late to register among the ‘first X passengers’. The next ‘first X passengers’ will be served by next shuttle in order.

The flowchart of service is shown on Figure 1.

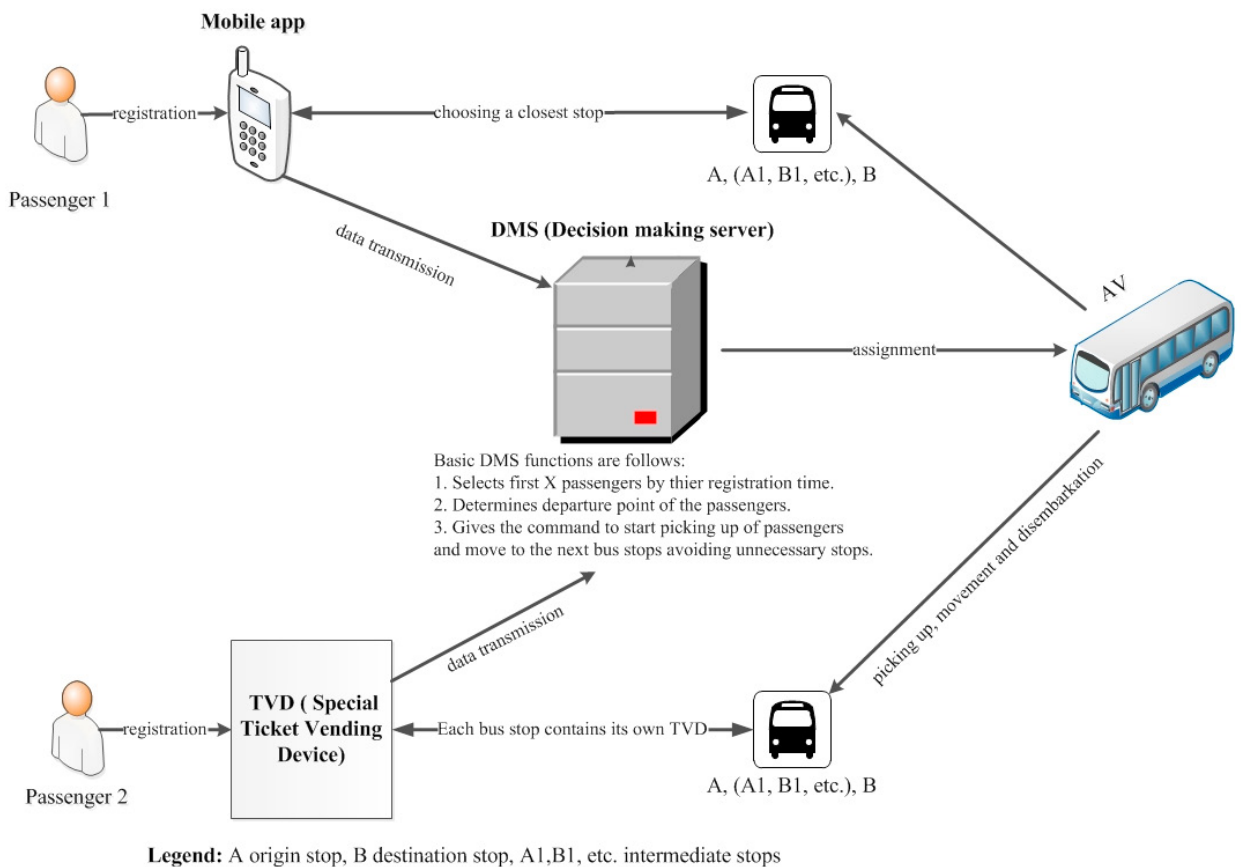


Fig. 1. Flow-chart of service.

As were mentioned before there are two intermediate points A1 and B1 on a route from origin point A and destination B. But it doesn't mean that AV stops at every intermediate point. Autonomous shuttle starts boarding and movement according to seat reservation data providing to DMS by mobile application or TVD located on each intermediate stops. Since the exact time and place (bus stop) of seat reservation maps the stochastic processes by

deterministic data, the ‘behavior’ of autonomous vehicles is not known. All commands and character of movement assigned automatically by DMS. Note that exact time and departure point of registered passenger are key data for DMS in order to define first X passengers. Thus, A V moves by direct path without any stops or it stops at several or at all intermediate points. Every trip has an electronic ticket with ID code which is received on the smartphone and scanned on boarding time by special device on board of A V. This is a guarantee that exactly first X registered passengers get on shuttle's board regardless of at which particular stop the tickets were purchased (regardless of pick up points).

#### 4. System model

In this section, we design the data model of the ARTS service. It is architecture for the system which can manage a fleet of A Vs to serve travelers for transportation services. The most important system components and processes are follows:

- passenger,
- seat reservation,
- shuttles assignment,
- shuttle.

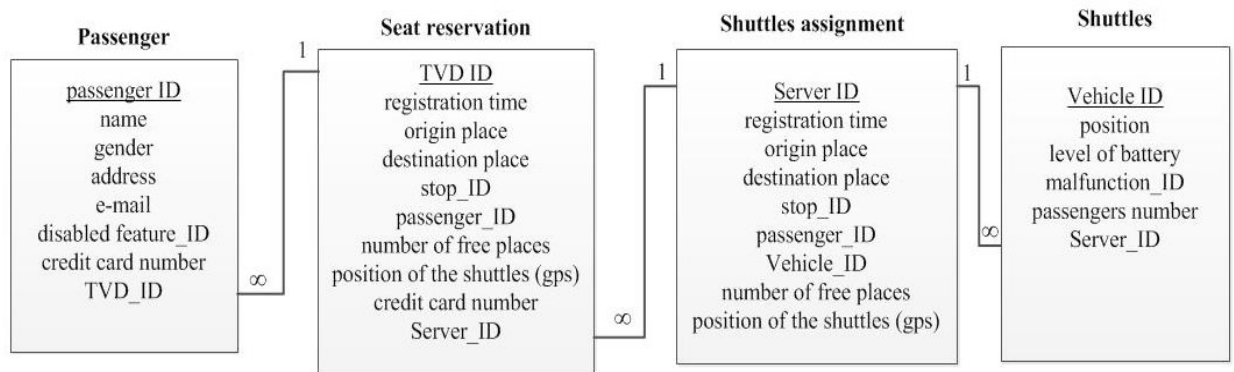


Fig. 2. Data model of service.

The above tables, forming the basis of the database, interact to each other and map the essence of ARTS service and its main processes.

#### 5. Conclusion

Planning and operation of future transportation will be much more complex than before. Therefore, new analysis and modeling methods should be elaborated and applied in order to facilitate the creation of new services based on A Vs. As the technological background is (will be) available, this tendency addresses enormous challenges towards system researchers, engineers and operators.

Among the main contribution of the paper we highlight the structural model. Our results may have high relevance for innovation and development. Key findings include the following:

- decreasing passenger idle time by elaboration of new ARTS system;
- decreasing idle cost by elaboration of new ARTS system;
- integration of PTOD and conventional public transportation service led to new well-organized and controlled service.

### *Lessons learnt.*

As the integration of information systems is an enormous and complex task, not only intuitively but also physically, future research is expected to proceed in several directions. Our future plans include:

- modelling of entire autonomous transportation system (passenger and freight too), with special regards to urban context, in order to reveal quantitative correspondences;
- elaboration of method for coordination of freight transport tasks and capacities;
- assessment of socioeconomic benefits (e.g. reduction in delivery prices).

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