Innovative transport systems and mobility services

Integrating autonomous vehicles into the public transport system

Altering transport system, Autonomous vehicle, Integration, Mobility service, System engineering

The developments of infocommunication and vehicle technology have altered the passenger transport system and given way to the emergence of innovative mobility services. During a Ph.D. research, the author focused on this alteration. The altering transport system, the planning and operational processes of new mobility services, the impacts of mobility services based on autonomous vehicles, as well as the automation opportunities of planning and operational functions were examined from the viewpoint of transportation engineering.

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Technical innovations, such as automation, have facilitated sustainable mobility developments (e.g. transitional mobility services, such as car-sharing, which blur the borderlines between private and public transport). The objective of such developments is the efficient management of resources as well as complying with user preferences. Automation can enhance operational efficiency and traveller's comfort. An automated system operates on clearly defined algorithms; an autonomous system is able to make decisions using its cognitive and self-learning abilities. As a result of technological developments, a smart mobility system can be introduced, which combines human knowledge, intelligence, and decision-making processes. Data and information have become key to decision-making. Consequently, the transport system can be considered as a special information system. A systematic revealing of elements and connections is required.

Studies in automation focus on the control and traffic issues of Autonomous Vehicles (AVs) [1]. However, passenger handling, operation, and maintenance can also be automatized [2]. Placing AVs into a wider-approach within the passenger transport system has moderately been emphasized so far. Albeit transport modes are altering, new methods are required for planning, organizing and operating transport. A new type of mobility service based on small capacity AVs emerges, which is shared, on-demand and accessible only with advance ordering via a mobile application [3, 4]. Mobility becomes more and more a pre-planned activity requiring proactiveness from the travellers. Human skills, the traveller's decision-making processes, and behaviour are also altering. Accordingly, the development of innovative information management methods and services supporting decision-making is required.

Therefore, the objectives of the research were to model AV-based transport systems on an urban scale, as well as mobility and information services, moreover, to elaborate system planning principles and evaluation methods. The focus was placed both on the operation and the traveller. Since the object of transport is the traveller, revealing expectations towards new mobility services is especially important. If the travellers' expectations are met, the adoption of new technology can be enhanced.

This summary briefly summarizes the most relevant results of the research, namely the model of smart mobility, the alteration in mobility services, the information system model for the planning and operation of AV-based services and the complex automation levels.

Methods

The methods applied during the research are as follows. A special method for analysing and modelling information systems was developed and implemented, which reveals structural and operational relationships in different resolutions (break-ups). Furthermore, relational data modelling was used for the elaboration of the database structure for the operation of AV-based mobility service. Multicriteria analysis, which is appropriate for complex systems, was used to model the smart mobility system. Weighted Sum Model was applied to determine automation levels. In order to obtain the right conclusions about the expectations towards AV-based mobility service, preferences were collected by a questionnaire survey. The connections between data groups were examined to determine the impact of each data group on each other. Both deductive and inductive logic was applied to draw conclusions.

Results

Smart mobility

New transport-related developments should be integrated into a system. This is called smart mobility, which is a decisive sub-system of the smart city; it realizes physical relationships between other sub-systems. It includes human knowledge, intelligence and a mechanism of decision-making applying information and communication technologies cooperating in transport infrastructure, in vehicles, and by travellers. The smart traveller is one of the smart mobility sub-systems and covers pedestrians, bikers, passengers and drivers as well. The structural and operational model of the smart mobility system focusing on the information management of the traveller was defined. The author found that the information management of a machine and a human are sim-

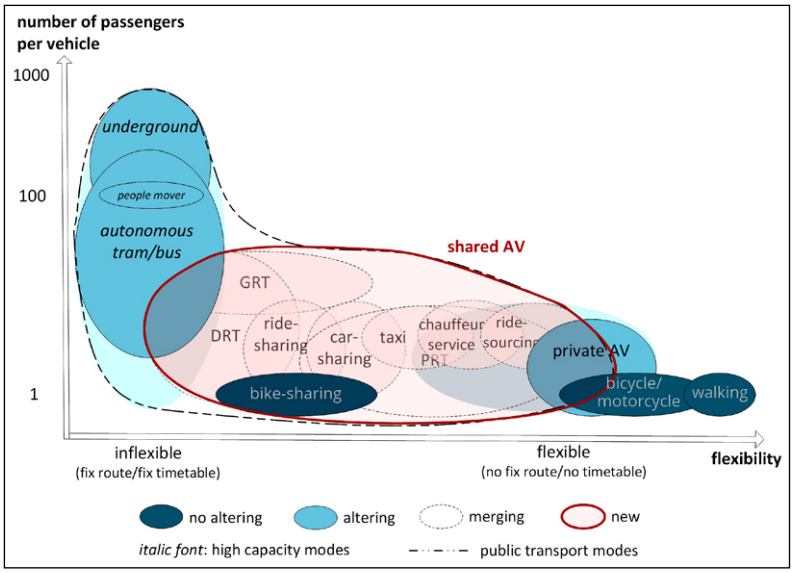

Figure 1: Alteration in transport modes

ilar. The machine system can be developed according to the revealed attributes of human information management. Consequently, information management can be supported and even replaced by an adapted info-communication technology.

Alteration in mobility services

Based on the literature review and situation analysis, the author identified the alteration in transport modes (see in *figure 1*). The envisioned future modes were depicted in terms of the number of passengers per vehicle and flexibility. Flexibility is a complex indicator depending on several aspects (e.g. spatial accessibility). Transitional transport modes and, even more, the majority of private car use can be replaced by a shared, on-demand mobility service based on small capacity AVs accessible only with advance ordering via a mobile application. The types and the characteristics of this service were defined. Among others, a rather flexible door-to-door type and a slightly less flexible feeder type linked to a high capacity line were also distinguished. The feeder type may run on a fix route or according to a fix timetable. As the capacity of the built infrastructure is limited, travel demands can be served efficiently by shared and feeder mobility services.

As AV-based mobility services are in an initial phase, the research elaborated on the structural and operational model of shared AV. The conclusion of the subresearch is that autonomy is a relative concept, since the coordination of several centres with different functions is required to plan, control and operate AV-based mobility services. That is why the integrated mobility management centre organizational unit was introduced with its defined tasks (e.g. management of operational data in an integrated database).

There are several expected impacts of shared AV; the impact fields were identified, and a model was developed to calculate the alteration in modal share. Stated preferences are used as input data by the model. It was found that private car use could be significantly reduced by the introduction of a flexible, shared, AV-based mobility service.

Planning and operation of AV-based mobility services

The planning and operation of shared AV require new methods. The aspects that cause alteration in conventional methods are as follows:

- more complex system structure,
- new and unknown technology,
- dynamism of the data and
- travellers' expectations towards more adaptive and sustainable service.

Travelers should also perform existing tasks in a novel way or should solve new tasks as well (e.g. ordering, boarding, payment). The role of personnel is reduced, and the driver's requirement can be ignored. New solutions are to be applied both in operation (e.g. charging) and in passenger handling (e.g. information provision). Functions with major alterations are real-time demand-capacity assignment, vehicle run planning, customized information services and vehicle charging.

The information system model was defined for the planning and operation of shared AV. Considering travellers' expectations is particularly important as the developments of such services are at an early stage. Accordingly, to define the model, the author determined the input data groups resulted from preferences and elaborated on the data collection method (questionnaire survey). It was found that travellers' socio-demographic and mobility habits influence expectations towards the mobility service based on AVs.

Automation levels

The calculation method of complex automation levels was determined for road-based mobility services. Control functions, service planning and management, as well as passenger-handling functions were considered. Four levels of automation were distinguished. Applying the method, the automation level of a mobility service can be described in a general and simplified way using only one value (*table 1*).

o.	name	description	the entity which makes decisions and executes
1	automation	All processes are executed by humans. The human has full responsibility, there is no direct machine support.	human
2	machine assistance	Decision-making is supported by the machine. However, the role of a human is significant.	human aided by machine
3	partial automation	A significant part of the processes is executed by the machine. The personnel monitor the processes.	mostly machine with human confirmation
4	full automation	Processes are completely operated by the machine. The personnel attend only as a supervisor	machine

Table 1: Complex automation levels

Automation impacts on the required human abilities. To determine the aggregated ability alteration, an assessment method was developed. The method considers every sub-function for the entire ride. It was found that the required human cognitive capability, all in all, decreases significantly as the consequence of automation and machine support, whereas requirements towards human abilities related to smartphone use rise.

Conclusion

The main contributions of this research were the developed models of smart mobility. Moreover, it was revealed and analysed the characteristics of smart traveller's information management and shared AV mobility service. Furthermore, it was elaborated on the information system model for planning and operating shared AV. In addition, complex automation levels for road-based mobility services were determined, and the alteration in required human abilities analysed. The results can contribute to facilitating and preparing the alteration of the transport system and the integration of AV-based services. They were already included in the curricula of subjects at Budapest University of Technology and Economics.

The most relevant key findings are as follows:

- Information management can be supported and even replaced by info-communication technology.
- Autonomy is a relative concept; coordination of several centres with different functions are required.
- According to travellers' preferences, private car use could be significantly reduced by the introduction of shared AV.
- Less human thinking is required because of machine support. Moreover, the human can be replaced in certain functions by the machine.

As automation technology is relatively new, experience is available neither from operators nor from travellers. Objective is to continue the development of evaluation methods for mobility services. The evaluation covers service quality, flexibility, features of integrity and automation, as well as customization. The research will continue in order to develop information services for supporting travellers' decision-making and also to develop AV-based mobility services. ■

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