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Challenges and prospects for unmanned urban transport

Anton Smirnov[1*], *Evgeniy* Smolokurov[1], and *Alim* Mazhazhikhov[1]

[1]Admiral Makarov State University of Maritime and Inland Shipping, 198035, 5/7, Dvinskaya str, Saint-Petersburg, Russia

Abstract. The article deals with current problems and prospects of development of urban unmanned transport. The rapid development of autonomous transport, artificial intelligence, and other information technologies makes it possible to introduce unmanned vehicles in urban public transport systems, primarily buses. The technological factors and obstacles for the development of unmanned public transport systems are summarised. Despite the fact that the capacity of such buses in current use is still small, a maximum of about 15 people, the routes are relatively short, and the use is mainly in test mode, the use of these vehicles, especially in large urban agglomerations, seems undoubtedly promising. The article presents an analysis of the main features and incentives for the development of unmanned public transport, gives a brief overview of pilot systems of autonomous public transport in European cities, considers obstacles to the development of these systems and the experience of development of unmanned public transport in Russia, and formulates assumptions about the future development of this transport segment. The first steps towards full autonomy and widespread use of unmanned urban public transport, however, this path will not be taken quickly.

1 Introduction

Taeihagh A., Lim H. S. M. Governing mention that "autonomous systems are characterised as systems capable of making decisions independently of human interference" [1]. Such vehicles can be divided into three groups: private unmanned vehicles, shared unmanned vehicles or taxis, and unmanned means of public urban transport, primarily buses [2]. In recent years, the topic of the development of unmanned transport has become increasingly relevant.

According to a study by the UN Department of Economic and Social Affairs, by 2050, two thirds of the world's population will live in cities. As shown in Figure 1, given the overall growth of the world's population, this will add 2.5 billion urban dwellers, a trend that will primarily affect relatively poor countries.

The estimated and projected urban population of the world, the most developed regions and the less developed regions from 1950 to 2050 is shown in Figure 1 [3].

* Corresponding author: smirnovab@gumrf.ru

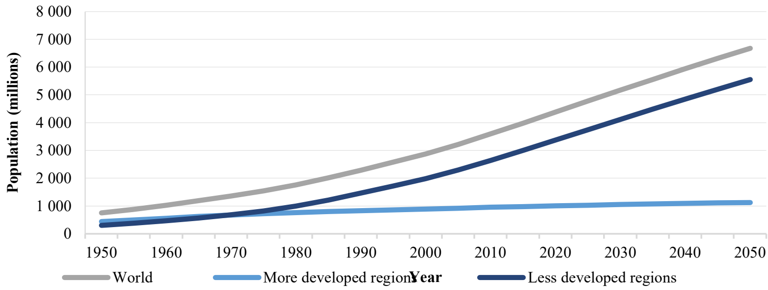

Fig. 1. Estimated and projected urban populations of the world, the more developed regions and the less developed regions, 1950-2050.

1.1 Relevance

The availability of fast, well-connected and affordable public transport is fundamental to making urban areas accessible. Large and densely populated cities depend on high-capacity public transport trunk lines to meet travel demand. The trunk lines are, in most cases, surface rail or the metro. However, as trunk lines are not directly accessible to the entire population due to the large size of large cities, additional more flexible solutions are required to bring passengers to them. Increased automation, i.e., the development of vehicles whose use requires minimal human involvement, is seen as one such solution.

The development of unmanned public transport is also relevant given the importance of the environmental agenda. Most countries worldwide have set quantitative targets for reducing greenhouse gas emissions over the coming decades. According to the European Environment Agency, traditional road transport is one of the main contributors to carbon dioxide pollution in cities, and 60% of road transport emissions come from private and public passenger transport. Yet, as Figure 3 shows, its relative negative impact continued to increase between 2005 and 2019. Unmanned public transport can contribute to a drastic reduction in the negative impact on environmental quality, not only in terms of greenhouse gases, but also with regard to the concentration of particulate matter and noise pollution in the air [4], as well as harmful emissions of sulphur and nitrogen compounds [5].

Figure 2 shows the sectoral trends and progress towards the 2020 and 2030 targets in the EU-27 [6].

Innovations in autonomous driving technology, according to some experts, will eventually allow citizens without a driving licence, such as minors, to gain access to a car. Hörl S., Ciari F., Axhausen K. W. Recent note that "induced demand and a wider user base will lead to an increase in the number of cars on the streets" [7]. Although the widespread use of autonomous vehicles can help to significantly increase road capacity, the rapid influx of new cars can lead to increased traffic congestion. This gives added urgency to the issue of developing not only personal but also public unmanned urban transport.

The potential for increased safety through the use of unmanned public transport is also a factor of relevance to the study. According to the US Department of Transportation (National Motor Vehicle Crash Causation Survey), drivers are the main cause of accidents in a large proportion of cases. Frequent causes of accidents include their inability to correctly recognise traffic situations, poor driving decisions or reduced attention to the road. The introduction of unmanned vehicles, although not an absolute panacea, may help to mitigate or eliminate most of the human errors associated with driving and make traffic flows safer for all participants [8].

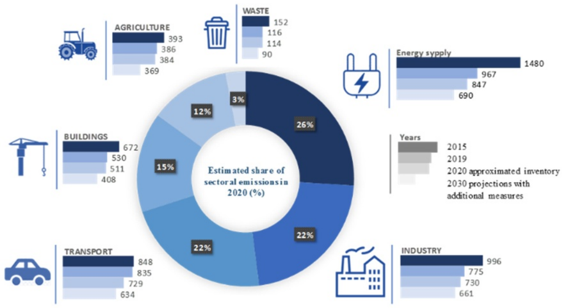

Fig.2. Sectoral trends and progress towards achieving the 2020 and 2030 targets in the EU-27.

Anton Smirnov, Evgeniy Smolokurov, Yuriy Fir mention in their article about a passenger train that derailed in Taiwan on April 2, 2021. "The accident killed 50 people and more than 70 passengers were seriously injured. In total, there were 494 people on the train during the accident. Earlier in Taiwan, there was an accident in 2018 when a train derailed in Yilan County. Then 22 people became victims of the accident and more than 170 passengers were injured". [9].

1.2 Literature review

Research into the development of unmanned urban public transport is a relatively new topic in the academic literature. Mouratidis K., Serrano V. C. note that some studies based on hypothetical models and simulations conclude that "autonomous cars - both private and shared - will result in increased vehicle miles travelled, shifts from public transport and active travel modes to more car travel, and more urban sprawl" [10]. Fraedrich E., Dirk Heinrichs, Francisco J., Bahamonde-Birkeb, Rita Cyganski note that the position dominating the research in recent years is that unmanned transport technologies "transport planners think that shared autonomous vehicles as a complement to public transport systems are more appropriate to support urban development strategies" [11].

Based on the fact that in traditional urban public transport systems, the bus is the main and most common mode of transport, the research on unmanned public transport also focuses on innovative buses. For example, Patrick M. Bosch, Felix Becker, Henrik Becker, Kay W. Axhausen analyse the different types of costs associated with urban transport, concluding that "Not only is demand bundling, when possible, more economic than point-to-point service, there is also a user preference for high-frequency, line-based service over dynamic services." [12]. Certainly, one cannot disagree with this position. A considerable part of research is devoted to certain aspects and consequences of functioning of unmanned public transport systems. Zhuang Dai, Xiaoyue Cathy Liu, Xi Chen, Xiaolei Ma consider "optimization where there are already running buses (i.e., including both HBs and ABs) on the transit line at the beginning of the studied horizon" [13]. Moradzadeh and Kaffafi examine unmanned public transport in the context of strategies for "urban development and minimisation of environmental damage through the use of low-carbon technologies" [14]. It should be noted that the implications of unmanned means of passenger transport for sustainable development are mainly analysed in terms of the dichotomy "public transport - private car". At the same time, insufficient attention has so far been paid to the comparative analysis of unmanned and traditional public transport, both in the context of environmental impacts and broader implications (e.g., an increase in unmanned buses may lead to higher unemployment rates among drivers). The topic of shaping unmanned public transport systems in relation to the triad of sustainable development (economic, environmental and social aspects) requires further study.

A separate block of scientific and analytical literature is related to the study of public perception of unmanned, including urban public transport. S. Nordhoff, M. Kyriakidis, Bart van Arem, R. Happee show that "Automated vehicle acceptance (AVA) is a necessary condition for the realisation of higher-level objectives such as improvements in road safety, reductions in traffic congestion and environmental pollution" [15]. Indeed, this is true. However, passenger attitudes towards innovations in public transport related to the introduction of unmanned vehicles have improved over time.

López-Lambas and Alonso, based on the analysis of focus group surveys, note positive factors in the development of the transport in question mentioned by passengers such as "Autonomous driving would be energy-wise more ecient and controlled. Vehicles would be programmed to minimise energy consumption by employing eco-driving patterns" [16]. However, there are still concerns and elements of negative public perception due to the high cost of unmanned vehicles and associated infrastructure, potential safety risks and possible increase in unemployment. Salonen and Haavisto show that "By explaining the clear purpose of driverless shuttle buses, the development of distorted perceptions can be prevented and interest and desire created" [17]. This view is also valid. For the analysis of other studies on the perception of unmanned public transport, refer to [18].

1.3 Problem statement

Analysis of scientific and analytical publications on the subject under consideration provides an opportunity to formulate the main theoretical and practical problems associated with the development of urban unmanned transport systems: identifying the advantages and disadvantages of the existing global pilot programmes of development of urban autonomous transport; identifying technological barriers to the development of the transport systems under consideration; identifying the features of regulation of unmanned transport sector and the necessary legislative and regulatory changes to ensure.

Taking into account the mentioned problems, the analysis of existing examples of using autonomous vehicles in urban public transportation systems, as well as the prospects for the development of this transport segment and the gradual replacement of unmanned vehicles by autonomous ones, are carried out within the framework of this study.

1.4 Aim, objectives and hypothesis

The purpose of this paper is to identify the future of urban unmanned public transport.

In order to achieve the goal, it seems necessary to perform the following tasks:
- to analyse the main features and incentives for the development of autonomous transport and specifically public transport at present;
- to consider the features and results of the functioning of pilot systems of autonomous public transport in the cities of the world;
- to investigate the technological factors and barriers to the development of unmanned public transport systems;
- to analyse the regulatory aspects of the development of the systems in question, to consider the available data on user attitudes towards unmanned public transport;

- to determine the prospects for enhancing the use of unmanned vehicles in urban public transport systems, taking into account various factors;
- to formulate recommendations on overcoming barriers to the development of unmanned public transport.

It is to be expected that unmanned will make effective use of the potential of autonomous vehicles in passenger transport systems, providing citizens with a convenient, comfortable and sustainable alternative to traditional mobility.

2 Methods

This article is based on theoretical research methods, including a comparative analysis of factors for the development of unmanned public transport systems; statistical analysis of data on the use of unmanned transport; the method of induction and generalisation, which allows drawing conclusions from a review of the operation of the first unmanned transport projects in some cities around the world; and the method of synthesis, which provides an understanding of the prospects for the development of autonomous transport systems taking into account various groups of factors.

The empirical methods used include expert evaluation and forecasting, which allow formulating recommendations regarding the use of unmanned vehicles in urban public transport systems, including those in Russia.

3 Results and discussion

Unmanned urban public transport (mainly autonomous minibuses) belongs to a new group of mobility tools. There are several differences between traditional mobility and its new automated models that could revolutionise travel in the following ways (Figure 3) [19]:
1. Ridesharing or car-sharing (Blablacar is an example) and the use of taxi services are merging with carsharing due to driverlessness.
2. Public transport by automation could become more efficient for more frequent trips with fewer passengers, and could also gain the ability to operate on-demand, making it more attractive relative to other types of unmanned mobility.
3. There is less change in the personal car segment; instead of a revolution, there will be an evolution of the traditional car, which can already brake, park autonomously, or hold a lane.

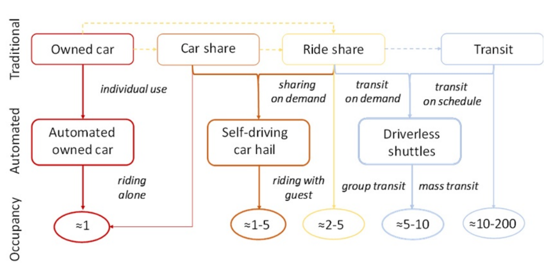

Fig. 3. Possible consequences of implementing automated driving into four contemporary modes of transport.

How exactly the balance between these trends plays out will depend on a number of factors, including the extent to which unmanned public transport programmes are actively supported and addressed. Over the past few years, the number of autonomous public transport pilot projects has increased rapidly. Such projects have begun to generate interest in various cities, universities and private companies. The development of autonomous urban public transport systems is currently at an early stage. Most of the projects are characterised by relatively short route lengths and small numbers of passengers carried. It should also be noted that most of the autonomous buses used in the aforementioned projects operate at a speed of around 12 km/h, and only in some pilot projects do the buses reach a speed of 20 km/h. The accelerated development of unmanned urban public transport is constrained by a number of factors, primarily technological.

Electrification and autonomy are the two key technologies enabling the formation of the next generation of unmanned transport systems. However, full electrification of public transport cannot yet be considered economically feasible due to the high cost of batteries and their low energy density (i.e. specific energy density) compared to fossil fuels.

The full electrification of public transport systems requires both vehicles and infrastructure to be adapted accordingly. Infrastructure must be upgraded with charging stations and vehicles equipped with high-capacity batteries. An important consideration in infrastructure development is the choice between large stations (centralised architecture) and many small charging points (distributed architecture). S. Sachan and N. Kishor in their paper "have allocated centralized charging station in distribution network with the objective of minimizing system costs including power loss and voltage deviation" [20].

In terms of vehicles, electrification can bring significant benefits associated with reduced pollution, lower noise levels, and improved safety. As already noted, the main disadvantage of using batteries compared to fossil fuels for transportation purposes is the lower energy density. In particular, the energy density of a diesel engine is about 13,440Wh/kg, whereas a lithium-ion battery has an energy density of about 220Wh/kg [21]. This means that in order to produce the same amount of energy as with fossil fuels, batteries would need to weigh about 60 times as much as a conventional engine. At the same time, electric motors have a higher efficiency (over 90%) than internal combustion engines (less than 30% in optimal conditions and less than 20% in normal use). Consequently, for the development of unmanned public transport infrastructure, it is important to focus on improving the energy capacity of batteries and the efficiency of the recharging process.

Sukhvinder P.S. Badwal, Sarbjit S. Giddey, Christopher Munnings, Anand I. Bhattand Anthony F. Hollenkamp note that "there are two variants of rechargeable Li-air technology- a non-aqueous and an aqueous form, both of which offer at least ten times the energy-storing capability of the present lithium-ion batteries" [22]. There is also the potential to improve the lithium-ion batteries that are already in active use. According to the US Geological Survey, there is enough lithium in the United States alone to equip more than 30 billion vehicles with lithium-ion batteries [23]. The current cost of lithium carbonate, primarily needed for battery production, and other materials used, such as cobalt oxide, manganese oxide, copper and aluminium, are relatively inexpensive and are widely available in nature.

To achieve the ambitious goal of safe and fully autonomous use in urban environments, vehicles must be equipped with a large number of sensors, essentially turning them into a kind of robot with new control functions such as reality perception and artificial intelligence (AI). The basic concepts related to modern autonomous vehicle technology are still controversial among experts. For example, which specific models of sensors and environmental perception systems to use, and which approach to take: traditional modelling or AI [24].

The problem of unmanned, or more broadly, autonomous control of any system has historically been solved by classical control theory, involving procedures for analysing a physical process and creating a controller for it. At the same time, a controller can only be

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created if the physical process is fully known. In the case of unmanned vehicles, the physical process can vary significantly depending on their geometry, loading and pavement properties (e.g., in the case of rain or snow).

Vishnukumar H. J., Müller C., Butting B., Sax E. conclude in their paper that "A future research aspect is to extend this methodology for complete autonomous testing and validation for the future generation of ADAS and autonomous vehicles with complete autonomously controlled environments in the real-world" [25]. However, such systems, built using classical control theory, lack the element of informed decision-making required to create a fully unmanned vehicle. In this case, an artificial intelligence approach may be useful.

The AI approach has demonstrated effectiveness in many practical scenarios. The most active debate is over the level at which artificial intelligence should be implemented in unmanned transport systems. The most conservative approach involves minimal use of AI functions, limiting its task to recognising surrounding realities, such as detecting pedestrians, cyclists and other vehicles, and recognising obstacles. In a more 'technological' approach, AI is also used for reactive navigation and obstacle avoidance, i.e. it is included as an element in safety-related decision-making. However, the question of the optimal level of AI implementation to ensure full vehicle autonomy remains open.

The successful implementation of autonomous public transport also requires the development and adoption of appropriate regulation. However, a fully unmanned vehicle cannot be licensed because it does not comply with European legislation, in particular UNECE (United Nations Economic Commission for Europe) rules and broader international law. UNECE rules require automated vehicles to be designed in such a way that the driver can, at any time, by a deliberate act, deactivate the automated driving function. Additional legal restrictions on unmanned vehicles, including public transport, relate to technical regulations in some countries that require seat-belts, mechanical brakes and other features not required for fully autonomous vehicles. The presence of a so-called 'vehicle operator' in the passenger compartment can solve some legal problems.

4 Conclusions

Unmanned public transport uses constantly evolving technologies that will nevertheless require lengthy testing and refinement before autonomous vehicles can fully replace traditional vehicles.

The analysis presented in this paper leads to the following conclusions:

1. unmanned vehicles are making significant changes to traditional mobility models and have the potential to revolutionise passenger transport. Exactly how the relationship between the trends associated with the development of unmanned transport will play out depends on how actively governments and businesses support research and testing programmes for new technologies and vehicles, and how effectively barriers to the introduction of fully autonomous transport are removed.
2. The development of unmanned urban public transport systems is still at an early stage. Most projects in this area are implemented in the format of testing and running-in of technologies for future scaling up
3. Development of autonomous urban public transport is hindered by a number of barriers, primarily technological and legal. The two main technologies enabling the formation of unmanned transport systems are electric propulsion transfer and autonomy.
4. Wider adoption of unmanned public transport is constrained by the need to develop and adopt appropriate regulations. There are legal issues related to licensing, liability in case of accidents, safety and other aspects of using unmanned vehicles.

5. Despite the objective difficulties, the number of projects in the field of unmanned public transport is growing, including projects of this kind being implemented in Russia. Nevertheless, such projects are only the first step towards mass use of unmanned vehicles in public transport systems on a par with traditional vehicles and, in the long term, the complete replacement of the latter.

However, the benefits and advantages of unmanned public transport in terms of cost-effectiveness, environmental sustainability, passenger convenience, high levels of safety (in the long term) and other factors make efforts to address the emerging challenges worthwhile. In this regard, particularly in Russian realities, it is recommended to:
1. to study and take into account the experience of pilot projects of unmanned public transport in other countries when developing policies;
2. to intensify the implementation of the state policy in the field of AI, including on the basis of Presidential Decree No. 490 of 10.10.2019 "On Development of Artificial Intelligence in the Russian Federation";
3. to support and provide sufficient funding for research related to new battery technologies, as well as other devices necessary for unmanned vehicles, such as sensors and sensors, and related infrastructure;
4. to take measures to amend the legal and regulatory framework governing the use of unmanned vehicles, including those intended for public transport, taking into account the key challenges presented in the article;
5. to incorporate unmanned public transport initiatives with other transport and urban development projects and programmes.

The implementation of the proposed measures will make it possible to effectively use the potential of autonomous vehicles in passenger transportation systems, providing citizens with a convenient, comfortable and sustainable alternative to traditional mobility.

References

1. A. Taeihagh, H.S.M. Lim, Transport reviews **39(1),** 103-128 (2019). DOI 10.1080/01441647.2018.1494640.
2. T. Litman, Autonomous vehicle implementation predictions: Implications for transport planning (2020).
3. United Nations. Department of Economic and Social Affairs. World youth report: Youth and the 2030 agenda for sustainable development (United Nations Publications, 2018).
4. European Environmental Agency. Total greenhouse gas emission trends and projections in Europe (2021).
5. European Union. EU Transport in Figures (2021). Publications Office of the European Union.
6. European Environmental Agency. Trends and projections in Europe. EEA Report No 13/2021 (2021).
7. S. Hörl, F. Ciari, K.W. Axhausen, Arbeitsberichte Verkehrs-und Raumplanung **1216** (2016). DOI 10.3929/ethz-b-000121359.
8. *National Highway Traffic Safety Administration et al. National motor vehicle crash causation survey: Report to congress.* National Highway Traffic Safety Administration Technical Report DOT HS **vol. 811,** p. 059 (2008).
9. A. Smirnov, E. Smolokurov, Y. Fir, Transport. Res. Proc. **61,** 139-146 (2022). DOI 10.1016/j.trpro.2022.01.023.

10. K. Mouratidis, V.C. Serrano, Transportation research part F: traffic psychology and behaviour **76,** 321-335 (2021). DOI 10.1016/j.trf.2020.12.007.
11. E. Fraedrich, et al., Transportation research part A: policy and practice **122,** 162-172 (2019). DOI 10.1016/j.tra.2018.02.018.
12. P.M. Bosch, F. Becker, H. Becker, K.W. Axhausen, Transport Policy **64,** 76-91 (2018). DOI 10.1016/j.tranpol.2017.09.005.
13. Zh. Dai, X. Cathy Liu, X. Chen, X. Ma, Transport. Res. Part C: Emerging Techn. **114,** 598-619 (2020). DOI 10.1016/j.trc.2020.03.001.
14. A. Moradzadeh, K. Khaffafi, Emerging Sci. J. **1(4),** 201-207 (2017). DOI 10.28991/ijse-01123.
15. S. Nordhoff, M. Kyriakidis, Bart van Arem, R. Happee, Theoret. issues in ergon. sci. **20(6),** 682-710 (2019). DOI 10.1080/1463922X.2019.1621406.
16. M.E. López-Lambas, A. Alonso, Sustainability **11(18),** 4986 (2019). DOI 10.3390/su11184986.
17. A.O. Salonen, N. Haavisto, Sustainability **11(3),** 588 (2019). DOI 10.3390/su11030588.
18. C. Goldbach, et al., Transport. Res. Interdisciplinary Perspectives **13,** 100504 (2022). DOI 10.1016/j.trip.2021.100504.
19. P.M. Smolnicki, J. Sołtys, Procedia eng. **161,** 2184-2190 (2016). DOI 10.1016/j.proeng.2016.08.813.
20. S. Sachan, N. Kishor, *Optimal location for centralized charging of electric vehicle in distribution network* in18th Mediterranean Electrotechnical Conference (MELECON) (2016). DOI: 10.1109/MELCON.2016.7495326.
21. B.A. Sandén, Systems Perspectives on Electromobility 2013 (2013).
22. S.P.S. Badwal, S.S. Giddey, Ch. Munnings, A.I. Bhattand, A.F. Hollenkamp, Frontiers in chemistry **2,** 79 (2014). DOI 10.3389/fchem.2014.00079.
23. National Research Council et al. The Role of the Chemical Sciences in Finding Alternatives to Critical Resources: A Workshop Summary (2012).
24. M. Bojarski, et al., *End to end learning for self-driving cars.* arXiv preprint arXiv:1604.07316. – (2016).
25. H.J. Vishnukumar, C. Müller, B. Butting, E. Sax, *Machine learning and deep neural network—Artificial intelligence core for lab and real-world test and validation for ADAS and autonomous vehicles: AI for efficient and quality test and validation* in Intelligent Systems Conference (IntelliSys), IEEE, p. 714-721 (2017). DOI 10.1109/INTELLISYS.2017.8324372.