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Opportunities for development of elevated electric transport in a large city

Oportunidades de desarrollo de transporte eléctrico elevado en una gran ciudad

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ABSTRACT

Modern large cities include both historically developed central parts and rapidly developing peripheral neighborhoods. Today, transport flows are formed not only by traditional bus, trolleybus, and tram routes, but also by significant fleets of taxis and private vehicles. An increase in traffic load and a shortage of parking spaces significantly reduces the capacity of roads and negatively affects the environmental situation. Ensuring transport accessibility based on the development of underground urban transport, the metro, is accompanied by great labor intensity, time and financial costs. Residents of large cities try to use bicycles, electric scooters, monowheels for intra-city movements. However, in winter in Russia this type of ecological personal transport becomes less accessible. A promising option for the development of public transport for large cities with a significant length of the street network in the absence of the technical possibility of expanding the roadway, can be an elevated electric transport (monorail). Using the example of the city of Samara, where the level of automobilization in 2019 reached 344 cars per 1000 people, the possibilities of developing the transport system of a large city with the inclusion of a monorail transport section in such a system are considered. This innovative solution will improve transport accessibility and reduce the negative impact on the urban environment. The average payback period of the project will be 4.4 years.

Keywords: Elevated Electric Transport; Large City; Monorail Transport; Transport System.

RESUMEN

Las grandes ciudades modernas incluyen tanto partes centrales históricamente desarrolladas como vecindarios periféricos en rápido desarrollo. Hoy en día, los flujos de transporte están formados no solo por las rutas tradicionales de autobuses, trolebuses y tranvías, sino también por importantes flotas de taxis y vehículos privados. Un aumento de la carga de tráfico y la escasez de plazas de aparcamiento reduce significativamente la capacidad de las carreteras y afecta negativamente a la situación medioambiental. Asegurar la accesibilidad del transporte basado en el desarrollo del transporte urbano subterráneo, el metro, va acompañado de una gran intensidad de mano de obra, tiempo y costes económicos. Los habitantes de las grandes ciudades intentan utilizar bicicletas, patinetes eléctricos, mono-ruedas para desplazamientos dentro de la ciudad. Sin embargo, en invierno en Rusia este tipo de transporte personal ecológico se vuelve menos accesible. Una opción prometedora para el desarrollo del transporte público para las grandes ciudades con una longitud significativa de la red de calles en ausencia de la posibilidad técnica de ampliar la calzada, puede ser un transporte eléctrico elevado (monorraíl). Usando el ejemplo de la ciudad de Samara, donde el nivel de automovilización en 2019 alcanzó los 344 automóviles por cada 1000 personas, se consideran las posibilidades de desarrollar el sistema de transporte de una gran ciudad con la inclusión de una sección de transporte en monorraíl en dicho sistema. Esta innovadora solución mejorará la accesibilidad del transporte y reducirá el impacto negativo en el entorno urbano. El período medio de amortización del proyecto será de 4,4 años.

Palabras claves: Transporte Eléctrico Elevado; Ciudad grande; Transporte en monorraíl; Sistema de transporte.

1. INTRODUCTION

As a result of intensive automobilization, the road capacity of many large cities is almost depleted. Samara is an good example that illustrates the complicated traffic situation in many Russian cities. That city reached the automobilization level of 344 cars per 1000 residents in 2019. Because of the limited capacity of the urban streets, this regularly leads to traffic problems (traffic jams and accidents), reduces the route speed of the public transport. The studies show, that peak loads complicate the situation significantly (Basharkin y Kholopov, 2019). The public transport is not able to provide the existing passenger traffic with the quality service. Today the city has almost exhausted the possibility of reconstructing streets in order to expand the roadways, and this is a problem for all of the types of ground transport.

The area of roads is less than 15% of the total building area in the city of Samara. If we compare it with other cities (Washington, for example, where this figure is 50%), we understand that the city has serious difficulties for its further development, taking into account the fact that there are almost no through street highways in the city. The improvement of traffic light regulation, the use of navigation systems by drivers, the allocation of special lines for public transport, the arrangement of underground parking lots and bans on entering certain parts of the city, and even the construction of two multi-level interchanges for the World Cup in 2018, are only temporary effects. One of the key problems in Samara is the lack of modern roads in the longitudinal and transverse directions, which would facilitate the choice of alternative routes by automobilists in the event of road transport and municipal accidents, traffic jams. Poor infrastructure development and unfavorable weather conditions in the autumn-winter-spring period hinder the development of ecological personal transport in Samara (bicycles, electric scooters, monowheels), which is becoming an innovative trend in foreign countries.

The existing busy roads of the longitudinal direction (Moskov highroad street, Novo-Sadovaya Street, Pobeda street, Gagarin street) could be relieved by the Central highway, but its construction is constantly postponed due to a lack of funding (Vasilyeva y Dolgikh, 2018; Vlasov *et al.* 2014).

The analytical stage of our study and results of own developments show that a problem of passenger transport may be improved only in the case of the construction of off-street transport. It should be also accompanied by the organization of intersections at different levels. This is important because the further expansion of the roadway of the urban streets is almost impossible today.

Automobilization and active point development have also adversely affected the environmental situation in the city: an increase in noise load, emissions of pollutants, and a decrease in the area of green spaces. Comparative characteristics of emissions of pollutants by different types of transport are given in the study (Basharkin y Kholopov, 2017).

A significant increase in average traffic speeds and an improvement in the environmental situation can be achieved by creating off-street transport (underground or aboveground). However, the metro, which provides a capacity of up to 40-50 thousand passengers per hour, is developing very slowly in Samara, which is associated with time-consuming and expensive works. In addition, the operation of the metro, which historically turned out to be disconnected from bus stations and the railway station, becomes very expensive.

The application of electric overpass transport in Samara will relieve the city streets from the dense network of existing land transport routes. This type of transport as a separate track structure will increase the average speed of traffic and reduce the number of accidents.

2. METHODOLOGY

The General Plan for the development of the city of Samara became the basis for developing solutions for improving the transport system. It reflects the territories of promising residential development, highways of citywide and district significance, and transport interchanges. In the course of the study, generally accepted methods were used. Among them are monitoring the intensity and composition of traffic flows, including using the Yandex-traffic service, studying the demand for urban public transport according to the criteria of occupancy and waiting time, analyzing literature and statistical data, studying documentary information about reported and planned transportations, comparative analysis of technical and economic characteristics of transport vehicles, calculation methods, and the method of expert evaluation.

3. LITERATURE REVIEW

Analysis of the literature shows that the construction of more roads in large cities often does not solve the problems of traffic jams, since the improvement of urban transport infrastructure provokes an increase in the number of cars in personal use. This trend leads to increased emissions of pollutants and inefficient use of energy (Siu, 2007). Today, transport flows in large cities include not only traditional bus, trolleybus, and tram routes, but also significant fleets of taxis and private vehicles. An increase in traffic load and a shortage of parking spaces significantly reduce the capacity of roads, which negatively affects the environmental situation.

The study (Trofimenko *et al.* 2019) presents a model that characterizes greenhouse gas emissions from road transport, attempts are made to create simulation models of intersections to regulate traffic and increase through capacity (Kozlov y Avsievich y Barotov, 2016), and other approaches to eliminating traffic jams (Lagerev *et al.* 2017).

As possible solutions to the problem, the use of railway tracks passing through the city for the implementation of "urban electric train" projects, the development of high-speed tram lines, and the introduction of electric buses are considered (Basharkin y Kholopov, 2019; Basharkin y Kholopov, 2017). Special attention should be paid to the issues of organizing the movement of people with disabilities in the urban environment (Safronov y Safronov y Mochalin, 2018).

Ensuring transport accessibility based on the development of underground urban transport, the metro, is accompanied by great labor intensity, time and financial costs. In Russia, this type of urban transport has proven itself well in Moscow, St. Petersburg, Kazan, and Yekaterinburg. However, in Samara, the development of the metro is extremely slow, and in Omsk it is completely stopped.

A number of countries are abandoning the traditional metro in favor of a cheaper option – the rapid tram. There are underground tram lines in many cities (Stuttgart, Antwerp, Charleroi, Brussels, San Francisco, Vienna, etc.) (Safronov y Safronov y Semenova, 2016). The implementation of the monorail system in the Greater Colombo area reduces the time spent on road and reduces the negative impact on the environment (Manoratna y Kawata y Yoshida, 2017). It is suggested to duplicate existing roads in large cities with light air lines (Korytov, 2018). The possibilities of using monorail systems in Russia are studied in studies

(Anfilofev et al., 2013; Lagerev y Nemchinova y Nemchinova, 2013). At the same time, it is important that transport facilities do not impair the aesthetic appearance of cities (Pavlova, 2016).

4. RESULTS

The development of passenger transport in Samara is associated with the desire to overcome the heavy workload of existing street highways and the accompanying significant air pollution. At the same time, monorail transport has an undoubted competitive advantage. This is an elevated electric transport that does not interfere with the movement of other types of transport and does not experience interferences from them. In addition, monorail transport provides revealing the street highways. This is a progressive high-speed, high-performance and economical form of public transport.

In comparison with bus traffic, the option of organizing a monorail passenger road raised to a certain height above the ground in the city has the following advantages:

- the monorail line does not depend on the terrain and can be chosen most efficiently,

- relatively low energy consumption (no delays at crossroads),

- absolutely reliable transport type – high resistance to wind loads, as well as a high degree of reliability in all climatic conditions,

- minimal interference with the natural environment and the ecological situation of the region during construction and operation process.

The proposed passenger transport system - suspension-type monorail on the route "Railway station" - metro station "Moskovskaya" - "Central Bus Station" is designed to transport the following passenger flows:

- residents of the regional center arriving in Samara by rail,

- passengers arriving in the settlements of the Samara region by rail and following the transit through the bus station,

- residents of the regional center, departing from Samara by rail,

- passengers departing from the settlements of the Samara region by rail and making their way through the bus station,

- the population following the places of mass recreation, as well as cultural and shopping centers,

- residents of the regional center traveling to their destinations with transfers to metro trains and other types of transport.

This route may be used for sightseeing tours. So tourists and guests of the city could see the main sights of the city. It should be noted that the proposed route of the monorail suspension road is located in a relatively flat topographical area, but intersects several urban highways that are extremely loaded with various urban transport, including trams, and has some other ground obstacles, which does not allow the construction of an autonomous direct high-speed highway.

Observations of passenger traffics on this section show that this direction of transport traffic in the city is very congested. Taking into account the number of residents of the Samara city, the number of passengers transiting through the railway and bus stations, as well as the mobility of the local population, we estimated the work of passenger transport in the amount of 10.8 million trips per year in one direction (Anfilofev et al., 2013).

The existing technical and topographical conditions determined the preliminary choice of the route, which has the following characteristics:

- begins near the railway station on Krasnoarmeyskaya Street (the final stop point "Railway station"),

- it runs along Krasnoarmeyskaya Street to Uritsky Square, where the first intermediate stop "Uritsky Square" can be organized, here it is possible to replenish the rolling stock with additional passengers following from shopping centers located on Sportivnaya Street»,

- then, in the area of the square located here, it makes a 90-degree turn to the left, goes to K. Marx Avenue and reaches Dachnaya Street, to a second intermediate stop "Dachnaya Street"»,

- after that, it follows Marx Avenue, where at the intersection with Gagarin Street, it is necessary to make the third intermediate stop metro station "Moskovskaya" (here it is possible to organize the transition to the metro station "Moskovskaya»),

- following along Marx Avenue, it is suggested to make a fourth intermediate stop "Revolyutsionnaya Street" at the intersection with the street of the same name,

- further along Marx Avenue, the highway reaches Aurora Street, where it turns towards the bus station and here has the final stop "Bus Station". The road diagram is shown in Fig. 1.

At the final stopping points, there are points for the current inspection and the carriage standing, and the transition of the driver to the opposite head cabin, since the carriage does not turn around at the final point, but changes the direction of movement to the opposite.

This organization of two-track traffic provides for the creation of special railroad switches at the end points of the transborder type, which take on their track section the rolling stock, disconnect the track structure of the railroad switch with the track structure of the arrival route, transfer to another direction, connect the track structure of the railroad switch with the track structure of the departure route, fix this connection, and the rolling stock goes in the return journey.

In the future, this will allow to extend the monorail route in one direction or the other, if necessary. Carriage standing is also necessary to compensate for the run-out (exit from the schedule), which can be caused by various unforeseen delays.

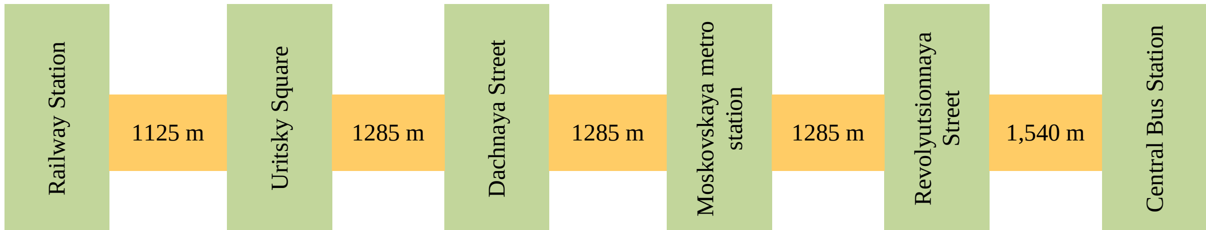

Figure 1. The scheme of the first stage of the monorail transport of the city of Samara

The construction of the suggested suspended passenger monorail can be carried out within 1.5-2 years. The estimated cost of the project implementation is 882 million rubles, the payback period of the monorail is 4.4 years on average. General information of the project (Anfilofev et al., 2013) is given in Table 1.

Table 1. Main features of the project

Length of the highway, km	**6.5**
Maximum speed, km / h	**72**
Capacity of the carriage, people:	
normal	**82**
max.	**111(125)**
Average travel distance, m	**4470**
Transit time in one direction, min.	**8**
Number of carriages on the road, number	**10**
Road capacity, people/hour	**6660**

The carriage of the passenger suspended monorail transport has two cabins for the driver, mounted from two opposite ends, is made of light alloys and is suspended by special nodes to two running bogies. The carts move along a special track structure laid in an open box-shaped span beam of a horseshoe shape, closed from above and at the side from snow and rain. Each undercarriage has 4 winch support wheels and 4 guided wheels, which ensure stable movement on the monorail beam.

In the event of a forced stop on the standing, passengers can exit the car through a hatch in the floor. For this purpose, an emergency ladder is used, which has a manually-operated winch and descends directly to the ground surface.

The suspension road supports are built taking into account two-way traffic. The welded traverse, reinforced on the supports, carries two track beams. Track beams and contact current-collecting tires are made up of separate elements mounted on the traverses. The minimum distance from the bottom of the carriage to the roadway is at least 4.9 m.

The use of pneumatic tires reduces shocks and shakes, improves the performance of the running qualities of carriages. To compare the environmental impact of monorail transport with other types of urban land transport and metro, a table of expert assessments is provided, where each type of transport is assigned relative places depending on its impact on the environment for each parameter. The lowest impact is 1 place, the highest is 2, etc. The greatest impact is the 6th place (Table 2). For the final assessment, the sum of seats is determined, which determines the total environmental impact of each of the considered modes of transport.

Monorail transport, as can be seen from the table below, is the most environmentally friendly in comparison with other types of urban transport: in terms of the gas content of the atmosphere, in terms of produced noise and dust, soil pollution and vibration. It occupies the smallest area and is safe for pedestrians. This means that in terms of the impact on human health, it is superior to other modes of transport, although the economic assessment of this aspect in the Russian Federation is not made due to the lack of appropriate criteria and standards.

Table 2. Environmental impact assessment of various transport types

Indicators	Types of transport					
	Bus	Tram	High-speed tram	Trolleybus	Metro	Monorail
Atmospheric gas pollution	6	3.5	3.5	5	1	2
Noise	3	5	4	2	6	1
Pedestrian safety	6	5	3	4	2	1
Dust	6	3.5	3.5	5	1	2
Occupied area	4	5	6	3	1	2
Soil pollution	6	4	3	2	5	1
Vibration	3	6	5	4	2	1
Total seats	34	32	28	25	18	10
Evaluation	**6**	**5**	**4**	**3**	**2**	**1**

To determine the possibility and payback period of construction, all expenses for the operation of the passenger monorail road were taken into account, including wages, taxes, energy costs, consumables, spare parts, etc.

Revenues from the operation of the proposed passenger monorail consist of passengers paying the cost of travel and advertising on the elevated road of the track structure and rolling stock, as well as from the rental of some premises.

Operating income exceeds operating expenses, so it is possible to determine the expected payback period for different costs per trip.

When determining the payback period of a passenger monorail road, the following statistics were used for the city of Samara:

- average daily filling factor of rolling stock – 0.36

- the average distance of a passenger route is 4.5 km.

The estimated payback period was from 2.9 to 5.9 years, depending on the cost of one trip taken into account in the calculations.

5. CONCLUSION

Taking into account the heavy traffic on Samara's highways and the fact that it is impossible to expand the ground road surface, a promising direction for the development of the city transport system is the inclusion of elevated electric transport in its composition. To make a final decision on the organization of the construction of the proposed passenger monorail transport, it is necessary to perform a feasibility study of these works in order to clarify the route, the volumes of passenger traffic on the proposed route, the upcoming capital costs and operating costs, and the equity participation in the financing of the project of budgets of various levels and private investors. In general, the appearance in Samara of a modern vehicle that solves the issues of passenger delivery is very attractive from an ecological and economic point of view.

REFERENCES

Anfilofev, B.A., Privalov, S.A., Kholopov, Yu.A. (2013), Monorail road - A promising option for solving transport problems of the city of Samara. In: Vasiliev, A.V. (ed.) ELPIT-2013. Ecology and life safety of industrial and transport complexes. Proceedings of the IV International Ecological Congress (VI International Scientific and Technical Conference), pp. 10-15. Samara State Technical University, Samara.

Basharkin, M.V., Kholopov, Yu.A. (2017). Ecological and logistic advantages of urban electric transport development in Samara. Vestnik Transporta Povolzhya 3(63), 73-77.

Basharkin, M.V., Kholopov, Yu.A. (2019) Approaches to creating a comfortable urban environment based on ecological and logistics solutions. Ecological Systems and Devices 2, 33-40.

Korytov, M. (2018). Aspects of using ground and above-ground transport for urban passenger transportation. Transportation Research Procedia 36, 341-346.

Kozlov, V.V., Avsievich, V.V., Barotov, A.Zh. (2016). Simulation model of the intersection with the possibility of traffic regulation. Science and Education to Transport 2, 44-48.

Lagerev, R., Kapski, D., Burinskien, M., Barauskas, A. (2017) Reducing a possibility of transport congestion on freeways using ramp control management. Transport 32(3), 314-320.

Manoratna, D.A., Kawata, K., Yoshida, Y. (2017). Environmental impact and travel time savings of a new monorail system in Colombo’s commuting traffic. Transportation Research Part D: Transport and Environment 51, 122-128.

Pavlova, L.V. (2016). Landscape and aesthetic organization of transport structures. Urban Development and Architecture 2(23), 96-103.

Safronov, E.A., Safronov, K.E., Semenova, E.S. (2016). Ways of solving transport problems in cities. In: Vitvitskiy, E.E. (ed.) Development of the Theory and Practice of Road Transport, Transport Logistics, pp. 284-291. Siberian State Automobile and Road Academy (SibADI), Omsk.

Safronov, K., Safronov, E., Mochalin, S. (2018). Methods of managing city transportations of passengers with disabilities. In: Abramov, A.D., Murgul, V. (eds). Siberian Transport Forum - TransSiberia 2018, MATEC Web of Conferences, vol. 239, 02008. EDP Science, Les Ulis.

Siu, L.K. (2007). Innovative lightweight transit technologies for sustainable transportation. Journal of Transportation Systems Engineering and Information Technology 7(2), 63-70.

Trofimenko, Y.V., Komkov, V.I., Potapchenko, T.D., Donchenko, V.V. (2019) Model for the assessment greenhouse gas emissions from road transport. Periodicals of Engineering and Natural Sciences 7(1), 465-473.

Vasilyeva, D.I., Dolgikh, E.A. (2018). Ecological aspects of urban transport infrastructure development (on the example of the city of Samara). Science and Education to Transport 2, 85-89.

Vlasov, A.G., Voronin, V.V., Vasilyeva, D.I., Most, E.S. (2014). Support framework for the development of the territory. Ecology of Urbanized Territories 2, 41-49.