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DEVELOPMENT OF CYCLING INFRASTRUCTURE BASED ON THE EXAMPLE OF URBAN AGGLOMERATION OF BELGOROD

Summary. This paper analyzes the real-world experience of using Bicycle traffic as a new way of supporting logistics traffic and reducing the load on the transport network of cities. As a result of this research, it was found that the real-world experience yields positive results and that cycling is actively becoming common in most of the world's cities. In the Russian Federation, not much attention has been paid to this in comparison with other countries; nevertheless, in recent years, this has been actively pursued. Research of the transport system supporting the city Stary Oskol of the Belgorod region and the Russian Federation allowed the authors to determine the main strategies for the development of a comprehensive and integrated Cycling network consisting of a Bikeway Plan as well as an economic assessment of its implementation. To justify this Bikeway plan, a simulation of travel time on public transport, calculation of the total travel time on various modes of transport and calculation of the walking time compared to the time spent in public transport were performed.

1. INTRODUCTION

Today, one of the main priorities in the transport sector is to find an alternative mode of transport to minimize the number of cars on the roads [1]. The introduction of cycling has become widespread. The most striking example of the successful introduction of this policy can be seen in the Netherlands [2-4]. There are currently over 18 million bicycles in the country and the total number of cyclists is growing every year. The state program for the development of two-wheeled transport in this country covers and solves all the problems associated with its distribution. The transport infrastructure is designed to allow cyclists to feel comfortable and safe on the roads. Almost all streets of major cities are equipped with special bicycle paths that, in general, are separated from pedestrian and transport routes. Highways are provided with bike paths to eliminate the occurrence of conflicts with other road users. The rules of the road in the country are designed in such a way that cyclists have an advantage, not cars.

In addition to positive examples of the development of cycling infrastructure, the transport network of Denmark can be studied. Today, many researchers, from ecologists to politicians and economists, are engaged in the development of cycling in Denmark [5, 6]. An integrated approach to the introduction of cycling has contributed to excellent results in improving road safety. According **to** statistics, road deaths

in Denmark have decreased by more than 10-fold [7]. The development strategy focused on creating a more attractive image of cycling, increasing the sense of safety and assigning priority to those who decided to switch to cycling [15]. Nowadays, in Denmark, more than 35% of all trips are made by bicycle. In addition to European countries, bicycles are a means of transportation in many Asian countries, including India [9]. Today, in relation to the context of the COVID-19pandemic, many cities around the world have begun to use bicycles as an alternative mode of transport, to gain access to basic necessities with minimum contact as opposed to use of public transport. With the aim of creating safe cycling environments, India has launched the «India Cycles4Change Challenge», which most Indian cities have already taken up.

Despite the positive dynamics of the introduction of bicycles into the transport infrastructure of cities, which is typical for many cities in European and Asian countries [10-12], in the Russian Federation, this has developed relatively recently, which is primarily due to its territorial location. The Russian Federation has a huge number of climate zones, ranging from an Arctic climate, where temperatures drop to - 60°C in winter, to a subtropical climate, where temperatures exceed 30°C in the summer [13]. A marked difference in weather conditions in the regions of Russia is also characterized by vast differences in the vehicles used by people [14].

Cities of the Russian Federation have recently considered the setup of bicycle infrastructure as an alternative mode of transport, since it has a number of advantages compared to the usual motorized modes of transport. In European cities, bicycling is generally an independent subsystem of public transport at all levels of transport infrastructure [15-16]. Adaptation of the road terrain for cycling in the already existing urban conditions requires adjustments; additional lanes and interchanges are required to ensure safe movement. Since 2015, according to the road code Russian Federation [17], cyclists have the right to move along the lanes allocated for public transport, which in turn can be unsafe and dangerous. Currently, with the aim of promoting cycling, Moscow has already developed a large number of innovative approaches to solve the existing problems.

According to statistics, the population of Moscow and the Moscow region in 2018 was more than 12.5 million people [18]. More than half of the population needs transportation services on a daily basis. About 8 thousand trips are made by drivers using their own bicycles and more than 550 trips were carried out by means of rented bicycles. These data combine only half a percent of all daily movements of citizens of the capital in the morning and evening rush hours [19]. The construction of new cycle paths on a city scale requires a large economic investment, which must be justified. Technical and engineering modifications require continuous work on the entire transport network of the city. To date, Moscow has already created more than 300 km of paths intended for bicyclists. However, not all of them are integrated into the complex infrastructure of the city for general use by all road users. In 2015, it was proposed to establish bike paths on a large scale from the Central districts of the city [20]. Thanks to the available data on the use of already active bicycle routes in the city mode, as well as due to the increase in the number of road users, the city authorities identified the main problems that can be encountered when designing new paths for cyclists. Based on the obtained statistical data, which include an analysis of the most popular routes, the types of accidents and the number of road accidents involving cyclists, organizational and legal measures were drawn up to solve the problems.

Despite the active introduction of bicycles into the transport infrastructure of cities of the Russian Federation, observed in Moscow and the Moscow region, the setup of bicycle infrastructure in other cities remains an open question that requires additional research. The creation of a transport infrastructure that is comfortable for movement on an environmentally friendly mode of transport should become one of the directions for the development of urban agglomerations, including Belgorod.

To achieve the main goal of the study - development of the logistics of cycling based on the example of urban agglomeration, within the framework of this study, a scientific approach was developed, reflecting the basic necessary procedures required before the introduction of the type of movement under consideration.

2. METHODS

2.1. Existing conditions for the development of cycling infrastructure

As a result of the active development of transport links between individual microdistricts and districts of one territory or subject in the Russian Federation, urban agglomerations are being formed, which, according to the definition, are a territorial grouping of urban and rural settlements, close but separated by spatial gaps [21]. This process provides prerequisites for the development of traffic management schemes, which now need to be considered comprehensively, taking into account possible changes in the transport infrastructure in connection with the process of the urbanization characteristics of urban agglomeration. In the Russian Federation, this is accompanied by the introduction of certain legal acts, according to which the main directions for the development of transport infrastructure within urban agglomerations are defined in the implementation of an integrated approach and the development of integrated traffic management schemes. One of the main directions, according to the presented scheme (Fig. 1), is the development of cycling infrastructure [22].

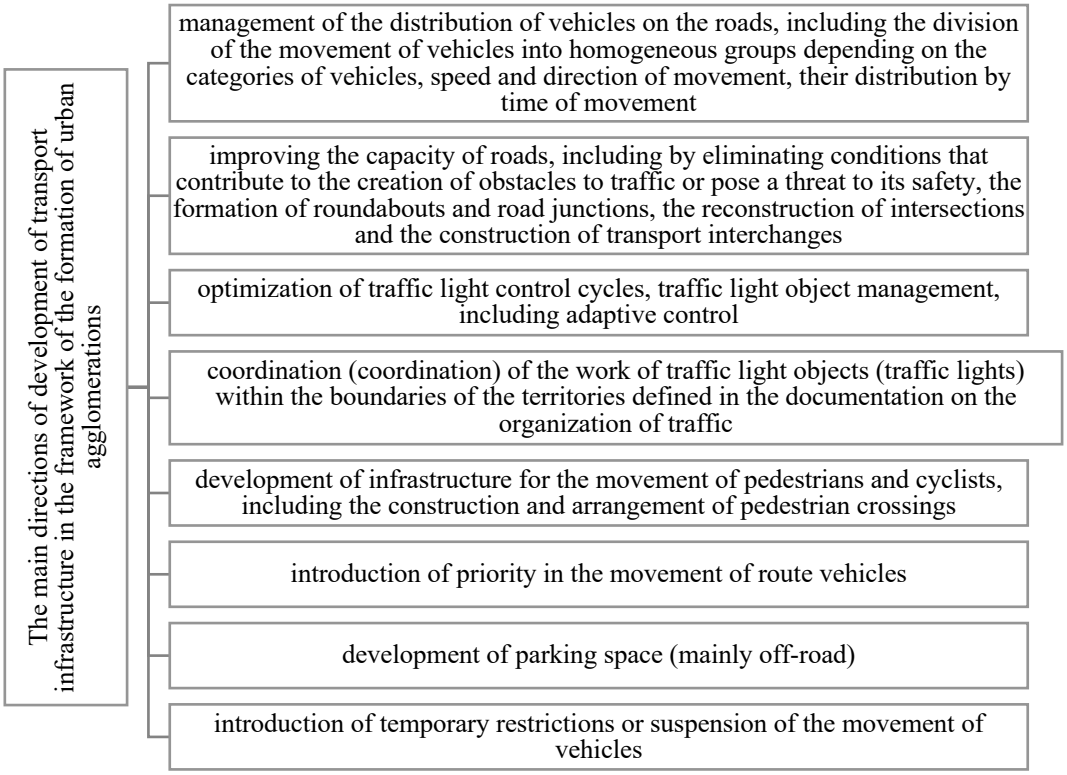

Fig. 1. Main directions of transport infrastructure development in the framework of urban agglomeration in the Russian Federation

Currently, the level of motorization in the country has significantly increased and continues to increase [23, 24]. In many cases, the road network cannot cope with the increased flow of passengers and cargo. Every year, the transport network of Russian cities develops and adapts to the new living conditions of the population. To maintain a certain direction in the development of the transport infrastructure of urban agglomerations (Fig. 1), we carried out a study on the development of bicycle infrastructure on the basis of urban agglomeration of Belgorod. In 2014, Belgorod city authorities started implementing the principles of communication policy and developed the program "Development of road transport infrastructure of the city of Belgorod", in accordance with which it is necessary to solve the main transport problems, including reducing the detrimental effect of road

transport through the use of alternative modes of transport. The goal of the ongoing project for the development of cycling in the city of Belgorod is to support the idea of urban cycling as an effective and nonconflict mode of transport in the urban space, as well as to create infrastructure and bike routes for mass use of bicycles. It is assumed that bicycles will become an alternative mode of transport in the city and will eventually be considered as full-fledged vehicles on par with buses.

As the main strategy, it was suggested that the widespread use of bicycles will create a sustainable urban environment that includes environmental, economic and social aspects. This will be achieved by:
- reducing parking problems, due to inadequate parking spaces;
- reducing the demand for transport spaces and thereby clearing the streets crowded with motorized vehicles;
- improving the quality of residential spaces in the city by reducing noise and environmental pollution;
- reducing the threat posed by vehicle traffic;
- possibility of joint use with public transport.

The strategic goal of developing the Belgorod region's communication system in the long term by 2026 is to increase the length of bicycle routes by 30% and the share of bicycle traffic in the total number of trips within the city by 10% [25]. It is possible to achieve these goals if the entire city is accessible by cycling and safe and comfortable conditions are created for cycling, comparable to that of other modes of transport. In particular, it is necessary to develop cycling routes that create a coherent and attractive network for cyclists. As part of the study, bicycle routes have been developed on the basis of a large urban agglomeration of the Belgorod region - the city of Stary Oskol.

2.2. Cycling infrastructure development

The city of Stary Oskol is a large agglomeration of the Belgorod region, which is part of the Central Federal district. From the Central cities of the Voronezh and Belgorod regions, there is a road that connects them, the length of which is 273 km, as shown in Fig. 2. This route passes through the cities of Gubkin and Stary Oskol, providing a continuous flow of passengers and cargo. The city of Stary Oskol is the administrative center of Stary Oskol city district, located at a distance of 156 km from the regional center, the city of Belgorod. The total area of the Starooskolsky district is 1,694 km2. Currently, about 260 thousand people live in the district on a permanent basis. The population density is 153 people/ km2 [19].

The transport infrastructure of the city has a rather rectangular appearance. Neighborhoods are delineated by streets that connect the road network. There are about 700 streets in the city. In Stary Oskol, there are four main transport routes that connect the entire transport network; see Fig. 3. Aleksey Ugarov Avenue is the central street of the city. This road originates from the R-189 Korocha-Gubkin-Gorshechnoe highway to the R-188 Stary Oskol-Novy Oskol highway. The avenue has a length of 8 km and runs through the North-Eastern district of the city, connecting the other streets in a single traffic flow. The road serves transit buses going to the city of Novy Oskol and the surrounding areas. The high passenger load on certain highways - Aleksei Butov and Ugarov Avenue is explained by the presence of a roach, which is a place of increased congestion. To increase the attractiveness of choosing a bicycle as a vehicle, provide a comfortable infrastructure for its movement [3-5]. Cyclists prefer to cycle in separate lanes away from vehicles or pedestrian paths. Therefore, the main factor that will motivate people to opt for cycling is to provide a dedicated space for cycling on the streets with the most traffic. Each side of the road must have at least 2.1 m of dedicated bicycle space with a certain degree of protection from vehicle traffic [26].

All bike paths along primary streets should have priority over adjacent roads, including intersections with secondary streets. Special attention should be paid to intersections. The intersection of transport and pedestrian paths is quite often the most emergency. A well-designed interchange reduces the number of decisions that must be made by each road user. As part of this study, it is proposed to gradually introduce bicycle paths into the city's infrastructure in the routes with the highest passenger traffic indicators; see Fig. 4.

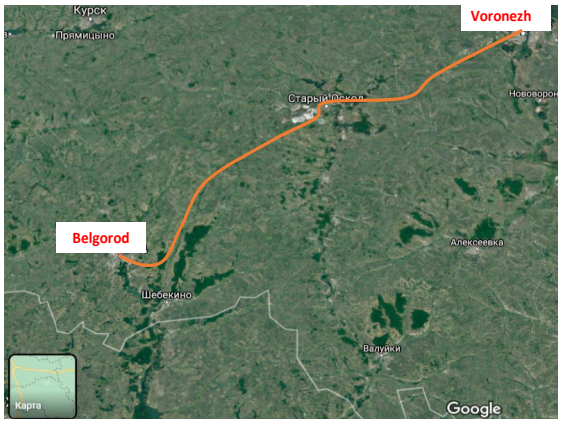

Fig. 2. Belgorod-Stary Oskol-Voronezh Route

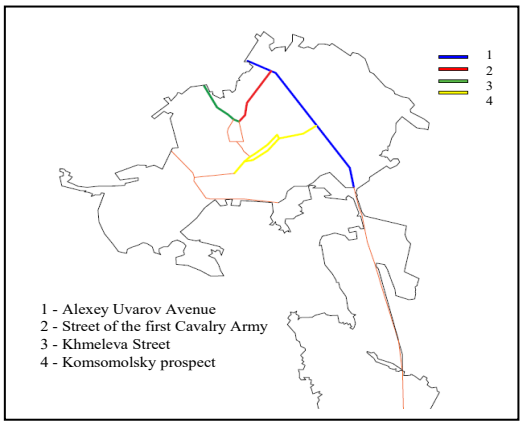

Fig. 3. Transport highways of Stary Oskol

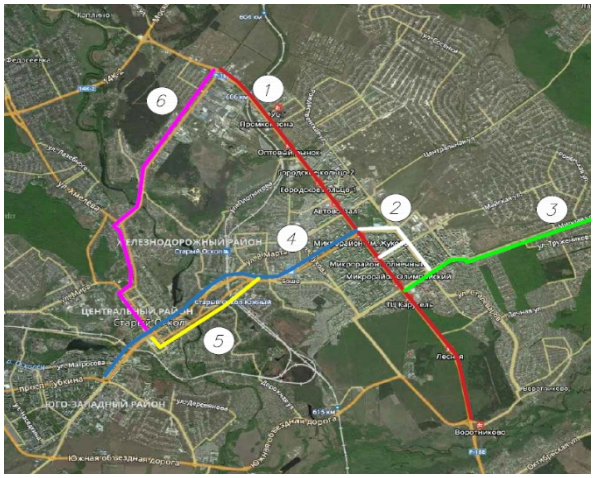

Fig. 4. Scheme for introducing cycling

3. ANALYSIS OF RESULTS

The first bicycle route with the help of the development of bicycle infrastructure will run along Ugarov Avenue. The length of the bike route along the Avenue is 9 km in two straight directions. The reference point for choosing a given site here is the availability of sufficient space for allocating a small plot of land for a bicycle path. Another key factor here is access to tram services. On this section of the introduced bicycle transport, there is access to bus stops.

Ugarov Avenue is the Central thoroughfare of the city; it passes through many centers of attraction, which will also be important for cyclists who will need to get to their homes, shops, schools and other institutions. The Avenue intersects a large number of streets that lead to residential neighborhoods of the city. Introduction of a second bicycle route, which is 3 km long (white color, Fig. 3), will allow cyclists to access the necessary places, as well as connect the route of their movement with intra-district and courtyard roads.

The third bicycle path, marked in green, also originates at the intersection with Ugarov Avenue and continues along Mirnaya street. This bike path leads to the territory of the city, where private houses are located, where there are often a large number of young cyclists who need high-quality and, most importantly, safe routes. The final destination on this route is the city zoo, where the number of visitors increases sharply in the spring and summer, and therefore, the need for high-quality bicycle paths increases. The bike path from the Avenue to the marked center of attraction is 8.5 km long.

The fourth bike path connects the "old" and " new" parts of the city. The path of the bike route goes along the Avenue of Youth, moving to the Komsomol prospectus. There is a bike path at a distance of 6 km.

The movement of cyclists in the opposite direction relative to the fourth track is duplicated by the fifth bike path, in the opposite direction, indicated in yellow. This bike path is 3 km long. On the selected sections, the introduction of bike paths will be relevant, as a route connecting inner-city parts.

The sixth Bicycle path, 6 km long, which is marked in purple, will connect Ugarov Avenue with Khmelev and Lenin streets. The need to introduce bike paths in the selected area is due to the large number of objects of attraction, including industrial and industrial ones.

To justify the development of 6 bike path routes, we performed a simulation of travel time on public transport, calculated the total travel time on various modes of transport and calculated the walking time compared to the time spent in public modes of transport (Table 1).

Table 1

Route development, their inputs and settings

	Route number					
	1	***2***	***3***	***4***	***5***	***6***
Route analysis using	Public transport	Bicycle	PT + BSS	PT + BSS	PT + BSS	PT + BSS
Origins	250-m grids			Shared bike hubs		250-m grids
Destinations	18 POIs				Shared bike hubs	
Walking speed	65 m/min			250 m/min		
Number of routes suggested	1	1	1	1	1	1
Means of transport used	All	Nonmotorized modes	All	Nonmotorized modes	All	Nonmotorized modes
Transfer safety margin	5 min					
Cost of walking time compared to time spent in public transport	1.35	Not used	1.35	Not used	1.35	Not used

We chose a weekday for research: Wednesday, August 12, 2020. We looked at time variations over the course of a single day by analyzing our proposed bike routes at two different times of the day: arrival times at destinations were set as morning (rush hour, 9am) and mid-evening (8pm). We did not study the differences between weekdays and weekends. We applied the standard values of the trip planner for basic settings, such as the transfer time margin (5 min), walking speed (65 m/min) and cycling speed (250 m/min).

We applied the default trip planner settings; therefore, we left everything unchanged on the first route (table 1, route 1). We used the Average tool to calculate the average route values for each origin–destination (OD) pair of the six suggested routes.

Simulation of travel time on a regular Bicycle (route 2): We restricted the proposed routes to conditional squares, with the four points of interest serving as the source entrances and the 18 points of interest as the destination entrances. It was determined that the average speed of cycling is 250 m / min, which to some extent compensates for the lack of the possibility of movement on other types of transport, for example, on route 2 (Table 1). In addition, certain parameters make it possible to introduce transition routes using mixed types of transport - bicycle and public. Since the ride planner database did not contain information about cycling infrastructure, we had to work with the pedestrian network, which is a clear limitation of the model. Simulation of travel time on public transport plus shared bikes (routes 3-6).

To model the ride time using the Bicycle sharing system (BSS), we first needed to identify a point near the end of the ride where cycling becomes a faster option than public transport. This is the moment when a passenger has to alight from public transport and ride the rest of the way to their destination on

a bicycle. To do this, we had to follow three subsequent routes (routes 3-6 in Table 1) and combine the results. We assumed that BSS is only available in the central part of the city; see Fig. 3.

We identified the last public transport stops on the proposed routes (for example, stops where passengers could use bicycles, if any), using the default route, but with the bicycle speed (300 m/min) set as the walking speed (table 1, route 3). We then saved the last public transport stop for each origin–destination pair for both times of day. Later in this article, these stops are referred to as shared bicycle junctions. In the next step, we calculated the travel time from shared bicycle hubs to POI destinations. We set the speed of cycling as the speed of walking, and walking as the only option (table 1, route 4). After that, we knew how much time it will take to get there by bike from the total cycling of the nodes to the destination. Because shared bike stations are not always located directly next to public transport stops or destinations, and because bike rentals and returns take time, we added "time penalties" to the travel time found in the previous route search. Because we assumed that walking time was closer to residential areas than in transport hubs, walking distances were based on observations and measurements in the city of Stary Oskol, Belgorod region. By reducing the travel time from nodes to destinations (route 4) and setting time penalties for the time of arrival at the destination (9 am and 8 pm), accurate knowledge of the time of day allows you to calculate the time of arrival at a particular transport hub.

Finally, we used the default settings to perform a different route search (table 1, routes 5 and 6) from the midpoints of populated squares (origins input) to common bicycle nodes (destinations input). The time of arrival at the nodes was determined based on the calculations performed at the previous stage. After searching for a route, we used the Average tool to calculate the average travel time for three alternative offers provided by the travel planner. The total travel time was calculated by summing the average travel time from the middle of the grid square to the General Bicycle node and the time from the node to the POI destination (including penalties).

Analysis of the impact of the system of intermediate Bicycle sharing with public transport showed that there is a reduction in travel time on combining public transport and cycling.

4. DISCUSSION

As a result of the model experiment performed, it should also be noted that the main criteria for the development of cycling routes are increasing the level of cycling safety, the possibility of continuous movement at a given speed, reducing the level of emissions and pollutants into the environment, simplifying movement around the city and coexistence without conflicts for all road users.

The key principles of building bicycle traffic and creating infrastructure are as follows: convenience and understanding of the created bicycle network, creating a favorable image of the use of bicycles, linking the introduction of bicycle infrastructure with the design of new and repairing existing transport routes and informing citizens about the introduction of bicycle paths.

Cycle paths are one of the healthiest and most efficient ways for people to get around. One bike lane can accommodate five times more people than a car lane, without causing air and noise pollution.

An experiment was carried out, as a result of which the travel time in public transport was simulated, the total travel time for various modes of transport was calculated and the cost of walking time was determined in comparison with the time spent in public transport. Intermediate bicycle-to-public transit systems have been found to show reduced travel times when public transit and cycling are combined. What can be an effective prerequisite for the introduction of transitional routes, with the possibility of using a bicycle type of transport and public.

5. CONCLUSION

On the basis of the results of this study, the following conclusions were formulated:

1. In modern cities, to improve environmental safety and due to the lack of space for movement and storage of motorized transport, cycling is becoming a rather relevant alternative. The introduction of

this type of non-motorized transport is actively developing in European countries, such as the Netherlands and Denmark, as well as Asian countries, such as India.

2. In the Russian Federation, the direction of the development of cycling infrastructure is developing relatively recently, but is already reflected in the main government documents.
3. The active development of urban agglomerations in the Russian Federation contributes to the development of an accessible transport infrastructure, which should include bicycle infrastructure. In view of the special advantage of cycling, previously designated as environmentally friendly and now confirmed during the global COVID-19 pandemic, as one of the socially distanced and accessible forms of non-motorized transport, it is a necessary measure.
4. As a result of the research carried out on the territory of the agglomeration of the Belgorod region - the city of Stary Oskol, 6 bicycle routes have been developed taking into account the development of an appropriate bicycle infrastructure - a separate designated place for movement and an alternative mode of transport in comparison with the passenger, which uses the transport infrastructure in conjunction with personal and freight transport.
5. The model experiment performed to determine the total travel time for various types of transport, public, bicycle and combined (public and bicycle), showed that when public transport and cycling are combined, the travel time is reduced.
6. Development of cycling infrastructure in modern cities and urban agglomerations and its combination, from an organizational point of view, with public transport will reduce travel time, especially within short distances, increase environmental safety and, to some extent, ensure social distancing.

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