The Use of the Decision Support System to Control Bicycle Transportation

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Abstract: City transport problems that today exist practically everywhere require from city authorities together with scientists to develop new ways of ensuring transport system's sustainability. One of such ways is promotion of non-motorised transport among the population. However, such problems as the lack of necessary bicycle infrastructure and the vulnerability of cyclists prevent population from shifting to non-motorised modes of transport. Authors have considered existing positive experience of implementing bicycles into city transport systems and came to the conclusion that the identified problems should be solved in a comprehensive manner. For this, authors suggest the Decision Support System (DSS) that will help to plan the development of bicycle infrastructure and to evaluate its efficiency and safety. Moreover, the proposed DSS allows building possible cycling routes and choosing the best one on the base of their road and ecological safety calculation.

1 INTRODUCTION

The problems caused by the urbanization growth and the need to ensure the population's safe mobility and the goods transportation have led to the strategies emergence to improve the safety and sustainability of the transport systems of cities and countries. These strategies include measures both on the choice of vehicles that meet safety requirements and on the infrastructure development more friendly to traffic participants. The measures indicated in these strategies can be clustered according to various criteria. According to the influence method, these are technical measures, that is, those associated with technical effects on systems, managerial, involving effects on the management object, and socio-psychological, associated with the human factor. Digitalization and intellectualization of industries and activity areas brings a decision-making new level in the complex systems management. This provides increased efficiency, safety and sustainability of such systems. For these purposes, a decision support system is created that allows using intelligent tools to verify possible solutions to a problem and select the optimal one among them.

The city's population mobility is provided by different transport types, among which motor transport, in particular using gasoline and diesel fuel, causes the greatest harm to the environment. Therefore, among the measures to improve the environmental situation in cities is the transition from individual to public and non-motorized transport. At the same time, public transport should become more environmentally friendly, using cleaner fuels such as natural gas or electricity. Cycle transport, in addition to reducing the burden on the environment, contributes to improving health, since physical activity reduces the risk of diabetes, obesity and cardiovascular diseases. Despite the obviousness of such changes in the transport systems of cities and megalopolis, there are problems that need to be addressed in order for these changes to be effective.

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The first problem is that 8% of all road fatalities in the European Union are cyclists, although there are significant differences between countries. Cyclists (like pedestrians) tend to be vulnerable in traffic, so ensuring the safety of walking and cycling is a top priority. Real and subjectively perceived safety can have an impact on the modal choice. This largely relates to such the most sustainable transportation methods as walking and cycling, as well as the of access to public transport possibility. At the same time, the safety of both the route itself and the interchange node for combined routes is considered. The needs of pedestrians, cyclists and motorcyclists, among whom, in total, 49% of all deaths due to road accidents in the world occur, are not given enough attention. Improving road safety in the world will be possible only if all approaches to road safety are taken into care the needs of all these road users. In Paris in 2016 at a special seminar on road safety of the International Transport Forum (Road Safety Seminar, 2016) a scientific report was presented entitled “Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System”. This report describes a paradigm shift in road safety policy, in accordance with the system safety principles. The safe system is based on the assumption that traffic accidents are predictable, they can be prevented, and you can go to zero road deaths and avoid serious injuries. This, however, requires a fundamental rethinking of management and the road safety policy implementation.

2 METHODS AND MEANS OF IMPROVING THE URBANIZED TERRITORIES’ TRANSPORT SYSTEMS EFFICIENCY

2.1 Non-motorized Transport and Conditions Extending its Use

The population will prefer cycling in the event that the clear advantage of using it is ensured. Today, in many European cities, such as Amsterdam, Copenhagen, Oulu, cyclists make up two thirds of all road users. In other words, most residents of big cities can change from car to bike. However, not everyone can ride a bike every day, so the bike is not a competitor, but rather complements public transport in urban mobility. Especially great potential for bicycles is represented by regular trips to and from work: in London such trips by bike account for about 2.5% of all trips to work, in Berlin - 13%, in Munich - 15%, and in Copenhagen and Amsterdam 36% and 37% respectively.

Such a high proportion of cycling trips is ensured by the Copenhagen politicians’ priority strategy, who, in order to create more favourable conditions for life in the city, have chosen the bicycle infrastructure development (Bredal, 2014). This has helped reduce the so-called carbon footprint, which in Copenhagen is one of the smallest in the world — less than two tons per person. However, the Denmark capital set a goal to become neutral in terms of emissions by 2025. The city has approved a project to equip bicycles with special sensors that report pollution levels and real-time traffic congestion (Smart City, 2017).

The study of Otero et al. (2019) is dedicated to assessing the health effects of basic BSS in Europe. The authors estimate the annual mortality dynamics as a result of physical activity, deaths from traffic accidents and air pollution, by analysing four scenarios. A quantitative model was built using data from transport and health surveys, as well as environmental and road safety records. The study involved BSS users aged 18 to 64 years. As a result, it was found that the twelve basic bicycle sharing systems (BSS) in Europe are beneficial for health and economy. Stimulating vehicles drivers to use the BSS can be used as a tool for disease prevention and health promotion.

One of the most common counterarguments against cycling are unfavourable climatic conditions. However, it all depends on the attitude to the bike lanes and on their priority when cleaning snow. This confirms the Oulu example, where the majority of residents move on bicycles, even at temperatures below zero during the deep winter. This is ensured by 800 km of bicycle paths (4.3 m per inhabitant), 98% of which work in winter, since the main bike tracks maintenance is more important than the roadway maintenance. The tracks parallel to the roadway are separated by a green stripe, which is also used for snow removal. Passages were built under the busiest intersections, and you can get anywhere in the city by bicycle (Tahkola, 2014).

There are technical problems to integration of bicycle transport with public transport. For example, among the companies of carriers is not well developed transportation of bicycles in public transport. Consider two options for transporting bicycles: inside and outside the bus or other transport. Most often, such methods are not available or not designed for use by a large number of cyclists. This is due to the introduction of additional changes in the design of public transport and reduce the area inside it, which leads to additional costs for carriers. As the

Copenhagen experience shows, the expansion of the bicycles model range designed for different population groups and different uses can increase the attractiveness of bicycle transport. Here you can rent not only bicycles of familiar designs, but also such models as: velomobile, cargobike, recumbent, electric-assist Long John, electric bicycle (Bicycle innovation lab, 2018).

Ways to increase the attractiveness of non-motorized transport are presented in Figure 1.

When planning a bicycle infrastructure, it is necessary to provide for the creation of bicycle lanes, the construction of parking areas and bicycle storage places. It is important to take into account the area features, as well as the population structure - the potential cyclists' part. Despite the large number of reseaches in the bicycle lanes design (Parkin and Rotheram, 2010; Larsen et al., 2013; Forsyth and Krizek, 2011; Rybarczyk, 2014), determining the terrain and modelling the topographic conditions for the designed or upgraded network of bicycle paths remains an urgent task. The most common method of designing bicycle paths is the method of overhead lines or shortest distances. Since, when designing a cycle route, it is not always possible to avoid the hilly terrain, the creation of bicycle lifts or electric drives for a bicycle will help solve the problem of overcoming steep ascents.

Currently, in many cities and countries where the authorities and the population are interested in the cycling development, strategies and development plans for mobility are being created. Along with technical solutions, such as the development and expansion of the bicycle infrastructure, considerable efforts are being made to improve the bicycle transport management and its integration into the general transport system of cities.

Ottomanelli et al. in their study (2019) propose an optimization framework for planning and designing a bicycle paths network in urban environments based on the equity principles and taking into account the set budget available. The novelty of the proposal lies in the fact that the goal function is aimed at minimizing the existing inequality between different population groups in terms of bicycle lanes accessibility. The proposed methodology is a reliable DSS (Decision Support System) tool that can help transport authorities / managers to select priority areas for their future investments related to bicycle infrastructure. This can help them identify cycle paths sections with a higher priority for implementation, especially with regard to preventing further inequality among population groups.

For large cities, the use of bicycles is a good solution to the last mile problem. This is one of the options for integration into the city's road network. The opportunity to get to / from the public transport stop should be provided on short sections of the path through the development of bicycle infrastructure, without which the integration of bicycle transport with public transport is impossible. This will increase the attractiveness of the bicycle as a means of transportation for most of the population. Sharing a bike reduces driving and increases cycling speed. Martin and Shaheen (2014) evaluate survey data in two US cities to find out who is moving to and from public transport as a result of sharing bikes. The authors analyse the socio-demographic situation associated with the modal shift through cross tables and four ordinal regression models. Common signs associated with switching to public transport include an increase in age, males, residence in areas of lower density and longer trips to work.

The identified problems should be solved in a comprehensive manner. In order to calculate the effectiveness proposed options at the design stage, as

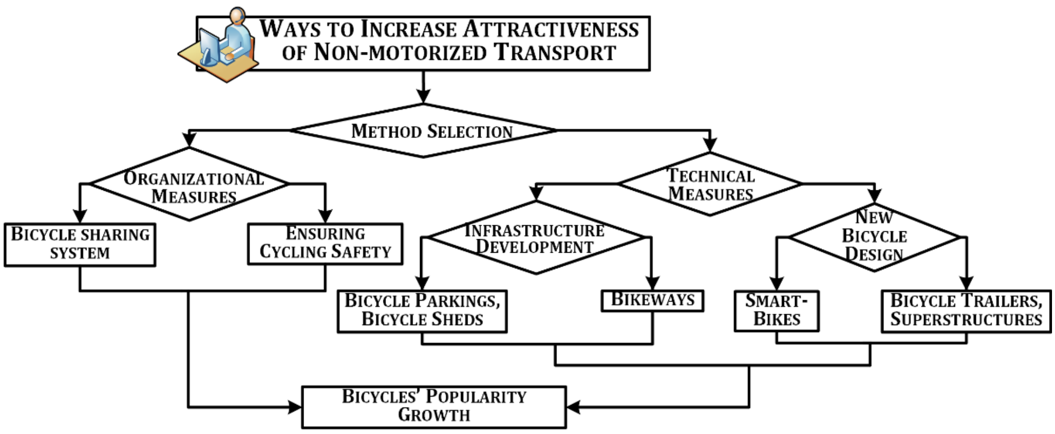


Figure 1: Measures to increase the attractiveness of non-motorized transport.

well as to verify the proposed solutions adequacy, it is necessary to create a DSS, the intelligent heart of which will be a modules' set to solve the abovementioned problems. Such DSS will create a unified information space and integrate positive experience and scientific research to optimally solve managerial problems of the city transport system.

2.2 Bicycle Sharing Systems: Problems and Solutions

More than 400 cities around the world have deployed or are planning to implement BSS. However, the factors that determine their use, and the degree of their rebalancing, are not precisely known. Knowledge of these factors would allow cities to design or modify their systems for increased use while reducing the cost of restoring balance. Ahmadreza et al. (2017) deal with usage data collected with the help of scenarios that record the bicycles availability at the station level every few minutes in urban areas of Barcelona and Seville. These data were aggregated to the county level, and the time dimension was aggregated to the hourly value. This allows us to calculate indicators of arrival and departure on a bicycle, as well as regional rebalancing factors.

The calculations results using real BSS data in Palma de Mallorca (Spain) are given in article of Alvarez-Valdes et al. (2016). Authors believe that despite the differences in systems, each has two main components: forecasting stochastic demand and routing, which must realize the forecast requirements in order to ensure user satisfaction. The authors, based on a joint analysis of these components, have developed a procedure that automatically reads the information in the system, predicts the requirements for withdrawal and return at each station for a specific time period. The proposed procedure was tested on a real BSS in Spain, and the results show its usefulness for solving everyday problems, as well as a planning tool that allows the user to evaluate alternative configurations.

Mingshu and Xiaolu (2017) have studied the BSS effect on reducing congestion in the city. The results showed that the BSSs characteristics depended on the city type. Compared to smaller cities, larger cities tend to have more sustainable public transportation. Since many of the docking stations are located close to public transport, the BSS encourages multimodal transport by connecting to public transport systems. Therefore, in larger cities, BSS can help replace short-distance road trips with cycling. During peak hours, this can reduce traffic congestion. Conversely, in smaller cities where there are fewer routes, the BSS can serve as an addition to public transport, providing links between various transit stops. The purpose of Kayleigh's study (2017) is to quantify the impact that the BSS has on passenger traffic. Understanding how the BSS and public transport are interconnected is vital for planning a mutually supportive sustainable transport network.

Ahmadreza et al. (2014) have examined factors affecting BSS use in Canada. Established in 2009, BIXI is the first major public BSS in Montreal. Using data collected in the form of per-minute readings of the bicycles availability at all stations of the BIXI system from April to August 2012, this study complements the literature on the bicycles sharing. The authors examined the meteorological data effects, time characteristics, bicycle infrastructure, land use, and attributes of the built environment on the station-level arrival and departure flows using a multi-level approach to statistical modelling that can be applied to other regions. The data obtained allow to identify the factors contributing to the increase in the use of the BSS in Montreal, and to provide recommendations regarding the station size and location decisions. The developed methodology and study's results can be useful for urban planners and engineers who design or modify BSSs for maximum utilization and accessibility.

Brian et al. (2017) argue that BSS changes attitudes towards cycling and sharing transport infrastructure. The article presents the using details one of the newest BSS in Ireland. The results show that, although Cork is a city without a strong cycling culture, BSS is often used. The results show that most trips were short and in most cases frequent. Frequent BSS users had the shortest travel time, including daily (or weekly) trips. The strong influence of weather conditions on the use of the BSS was also found. Under good weather conditions, the number of trips and their duration increase. The results of this article provide valuable insight into how a BSS works in a small city. According to the authors, more research is needed to understand the differences in smaller and larger cities, such as New York and London.

3 RESULTS AND DISCUSSION

Since the bicycle infrastructure development is a promising direction, which will require a roads situation periodic analysis, a DSS conceptual scheme was developed, containing data collection and analysis modules, simulation models (SM) and advice development module. AnyLogic 7.3.3 was used for the development of SM. Modules for data analysis and recommendation justification are implemented in Delphi 7.

3.1 Designing DSS for Managing the Bicycle Traffic Development

The qualitative integration of the bicycle infrastructure with the city's public transport system can be achieved through system solutions. One of such modules is designed to justify the effectiveness and economy of such integration and should provide the possibility of both strategic and operational management. Strategic objectives are defined for the long term. Criteria for the quality of integration will be increased safety, capacity and passenger traffic, as well as reducing the time to overcome the cycling route. Correctness of such information system is largely determined by the source information quality and the adequacy of the its processing method. This is ensured by following modules:

- collecting, storing and administering monitoring data for cycling and pedestrian flow parameters, quantitative and qualitative properties of bicycle infrastructure, transport system parameters;
- analysis of statistical and dynamic data;
- simulation models development and carrying out computational experiments in before / after situations (before - with parameters of the existing infrastructure, after - with changes in accordance with the recommendations received).
- making decisions for analysing and evaluating data and then developing recommendations (calculating the track width based on passenger traffic and the existing bicycle infrastructure capacity; calculation of the need to create recreation and repair areas, their number and parameters, etc.).

The conceptual DSS scheme is shown in Figure 2. The database is formed from:

- reference information, which is conditionally constant, as it is updated quite rarely, at specified intervals, or as needed.
- operational information - monitoring data of objects that change dynamically and characterize the transport system state over time;
- positive decisions that characterize the system's optimal state with certain parameters. These decisions are formed after the analysis performed in the intellectual module after computer experiments and after the verification appropriate results adequacy by the decision maker.

For data input, a user interface has been developed, including information input and adjustment windows (Figure 3).

3.2 Development of Intelligent Modules for Evaluating the Efficiency and Safety of Bicycle Infrastructure

The designed DSS is built according to a modular principle, which allows it to expand its capabilities using a single information base. Now, modules have been developed for assessing environmental performance and route safety. As an example, to test the methodology adequacy, the Naberezhnye Chelny city street-road network was used. The city specificity is in the separation of industrial and residential areas. Regular public transport routes between these zones do not exist due to inefficiency. Therefore, most industrial staffs prefer to use personal transport. In this regard, there are significant difficulties in delivering the population to the main city's employer – PC KAMAZ: despite the alternative routes availability, congestion and traffic jams occur at rush hours. Cycling routes integrated with public transport routes to solve the "last mile" problem could improve the situation.

3.2.1 Calculation of Route's Ecological Efficiency

According to numerous studies, emissions and noise are the most dangerous pernicious effects of the vehicles operation. To study the potential for reducing the vehicles negative impact due to the cycling growing share, we examined the emissions and noise level at one of the Naberezhnye Chelny road network's critical sections. At the first stage, this areas simulation model was built with available transport routes and cycle paths in AnyLogic simulation modelling environment based on a discrete-event approach using a traffic library (Figure 4). Here red areas are marked with high traffic intensity. Then a survey of PC KAMAZ employees was conducted, which constitute the main flow of traffic participants in this sector. The results showed that only about 2% of respondents use bicycle transport. 24% of respondents are ready to use a bicycle instead of individual cars and as an addition to public transport while improving bicycle infrastructure (bicycle lanes, safe crossings at the intersection with roads, recreation and repair areas, self-service stations, secure indoor parking, rental centres at affordable prices).

Simulation with predictive parameters, reflecting

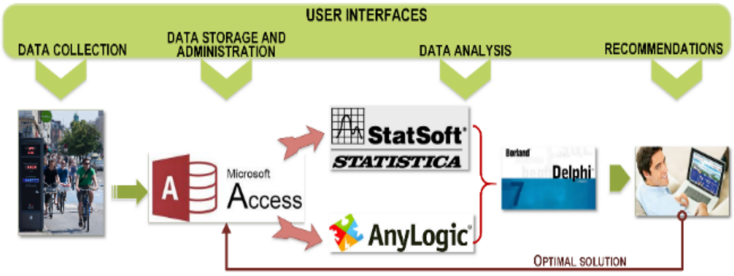


Figure 2: The conceptual DSS scheme.

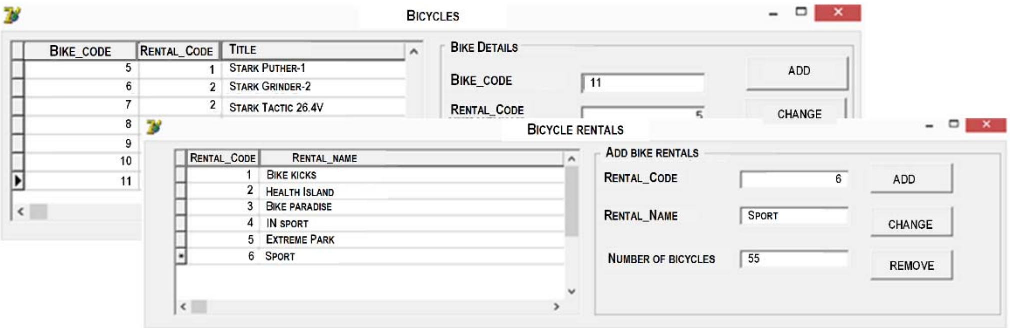


Figure 3: Information input and adjustment windows.

a decrease in the motorist's number in favor of an increase in the cyclist's number, showed a decrease in the vehicular traffic intensity, which will lead to a reduction in the negative traffic impact on the environment.

As a result, this will lead to a reduction in CO emissions by 20.0%, NOX by 20.7%, hydrocarbons by 8.9%, SO2 by 14.1%, the equivalent sound level by 9.1%.

3.2.2 Cycling Route Safety Calculation

When drawing up routes for urban movements, it is necessary to choose the safest of the possible routes, taking into account the traffic participant characteristics. Categorizing the route can be performed depending on various factors complicating traffic conditions. Depending on the movement type, routes in the city can be road, pedestrian, cycling and combined. The combined route, as a rule, includes the areas where the movement takes place on public transport, and the movement between the starting (end) point and the stop of public transport - on foot or by bicycle. These plots are estimated using criteria's different groups, since they may differ as traffic conditions on the plots, and priorities for different population categories.

Therefore, we propose a methodology for multi-criteria route safety assessment. Route assessment can be performed using a complex indicator, which is calculated by the formula:

$$K = \frac{\sum_{i=1}^{n} K_i \cdot \alpha_i}{\sum_{i=1}^{n} \alpha_i} \rightarrow min \qquad (1)$$

Factors that determine the safety of the route can be both objective (e.g., terrain, presence of unregulated intersections, etc.), and subjective due to the features and physical condition of the road user (age, health condition, etc.). Adequacy of the assessment will depend on the correctness of the selected factors and their combined inclusion. For example, the same route can be safer in the daylight than in the dark, in the summer than in the winter, etc.

Possible routes are evaluated on the base of this information. To do this a matrix of the given route options is constructed and then the overall routes' performance indicators are calculated (Figure 6). The value of the route safety indicator is calculated with provision for correction factors that depend on the physical condition and characteristics of the user.

Using the simulation models described above, a route safety assessment can be performed at the design or reconstruction stage. In addition, when changing the transport system parameters, such models can be used to assess the effectiveness of the route in terms of the infrastructure facilities use.

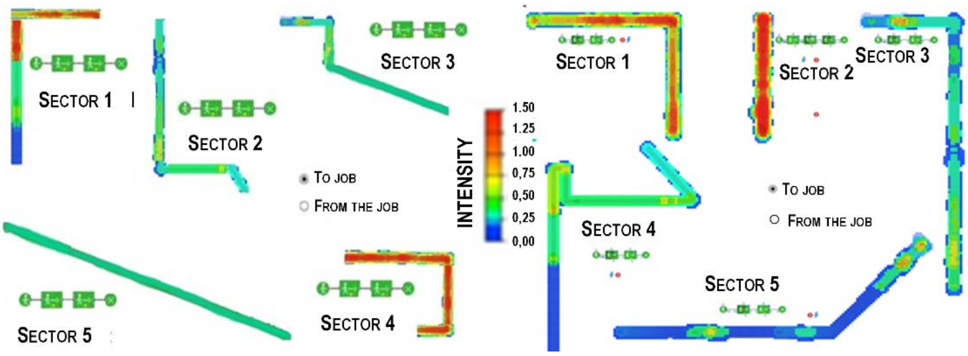


Figure 4: Simulation model of routes with current traffic flow parameters.

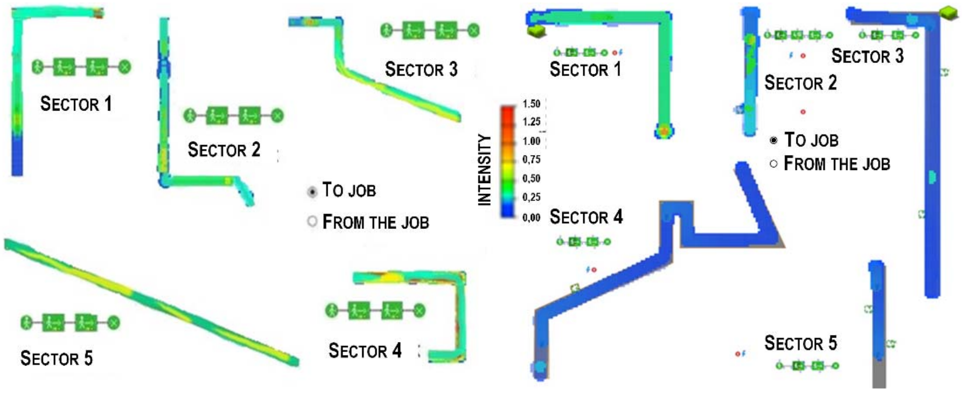
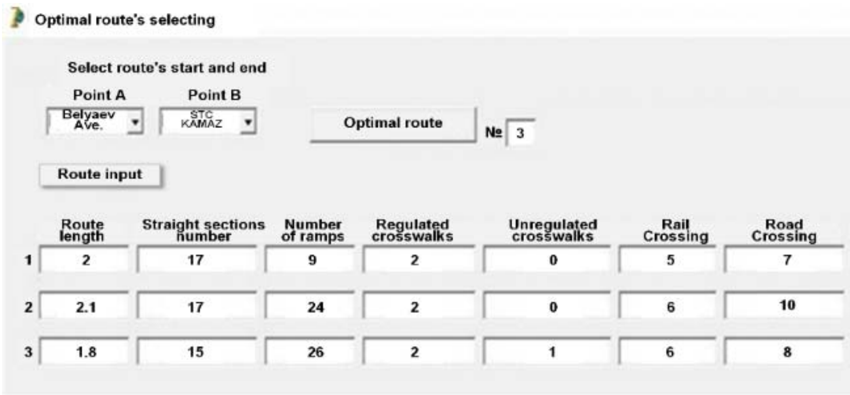


Figure 5: Simulation model of routes using cycling.



	Route length	Straight sections number	Number of ramps	Regulated crosswalks	Unregulated crosswalks	Rail Crossing	Road Crossing
1	2	17	9	2	0	5	7
2	2.1	17	24	2	0	6	10
3	1.8	15	26	2	1	6	8

Figure 6: View of the developed module.

4 CONCLUSION

The qualitative integration of the bicycle infrastructure with the urban public transport system can be achieved through the implementation of complex projects, so one of the DSS subsystems will become a module to justify such integration. DSS must provide both strategic and operational management capabilities. At the same time, the criteria for the integration quality will be increased environmental efficiency, safety, throughput and passenger traffic, as well as reducing the time to overcome the last mile. To ensure dynamic data collection for the information system, we need to use counters for cyclists and pedestrians. Such systems are widely used in different countries, as well as in different cities of Russia: for example, in Moscow, Kazan and Almetyevsk.

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