Indicator system for monitoring the development of urban bicycle transport infrastructure

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Abstract. Based on surveys of bicyclists and the study of foreign practice with regard to monitoring the development of bicycle transport infrastructure, scientists from Plekhanov Russian University of Economics have offered a flexible system of indicators to assess and plan the development of the bicycle transport infrastructure for the city of Moscow.

1. Introduction
A modern metropolis is developing according to a model that provides for reducing the environmental burden on the urban environment, which means the development of more environmentally friendly modes of transport. In addition to public transport, the practice of developing the urban environment in large cities provides for the development of bicycle transport infrastructure. Bicycles are one of the most promising personal vehicles to date. [1-3]

As studies [1] show, in order to increase the number of users of bicycle transport, a city needs to develop a bicycle transport infrastructure. The development of bicycle infrastructure entails an increase in the number of users of bicycles, and therefore reduces the environmental burden on the city [5-8], makes urban infrastructure more accessible. In addition to environmental problems, an increase in the number of users of bicycles solves the problem of low mobility of citizens [2].

Now in cities the most popular road transport [3-4]. However, the increase in the number of cars worsens the environmental situation, increases the accident rate, the number of traffic jams and noise levels. An alternative could be Bicycle transport. It has a number of undeniable advantages:
- reduction of harmful emissions into the atmosphere of cities;
- noise reduction;
- reduction of traffic jams in the city and time spent in them;
- less need for Parking spaces, as one Parking space, you can Park several bikes;
- budget savings on health care, as a result of greater physical activity of the population;
- significant savings on fuel for cars, as well as consumables and accessories;
- the possibility of more live communication with people and exploring new places and routes, which increases the tourist attractiveness of cities;
- provides an additional incentive for the development of related industries and creates opportunities for the development of small businesses;
- higher mobility of the vehicle compared to the car
Bicycle infrastructure projects require prior assessment of the intensity of existing Cycling, identification of the needs of cyclists, setting goals and tracking the implementation of these goals. In this regard, an urgent task is to create a system for monitoring the intensity of bicycle traffic.

Like any project, the development of a bicycle transport infrastructure in a city should have measurable indicators which are reflected in the monitoring system concept \[3\]. This paper will show what indicators should be measured to assess the achievement of the goal of development of the bicycle transport infrastructure in Moscow, thus increasing the mobility of the citizens.

2. Materials and Methods

In 2018, at Plekhanov Russian University of Economics, a large-scale study "Development of a methodology for assessing the intensity of cycle traffic and monitoring the use of bicycle infrastructure in the city of Moscow" was conducted [4]. This study also included fieldwork, namely, manual counting of bicyclists on the city streets, analysis of recordings made by the street surveillance cameras. To identify the assessment parameters, the experience of the Russian and foreign research projects was studied, in particular [9-15].

In addition to the cyclists count, several other parameters were evaluated that were taken into account when determining monitoring indicators.

Thus, changes of the bicycle transport infrastructure were evaluated using the monitoring method [16], the dynamics of bicyclist traffic intensity was analyzed by manual counting and video monitoring, and the perceived level of development of the bicycle transport infrastructure was studied using the questionnaire method.

The “quality loop” methodology has become crucial in identifying development indicators. Both the level of development and the satisfaction of participants in traffic and other subjects associated with the development of bicycle transport infrastructure were measured. The target, delivered, expected and perceived levels of infrastructure development were evaluated.

3. Results

As the study showed, the following indicators in the monitoring system for the development of bicycle transport infrastructure will contribute to achieving the goal - increasing the mobility of citizens:

1) Traffic intensity,
2) Security
3) Cohesion
4) Directness,
5) Attractiveness
6) Comfort.

Measurement of the cycling traffic intensity was aimed to assess the demand for cycle paths. It was measured by manual or automatic counting at metering points. The indicator dimension can be defined as the number of bicyclists per hour, bicyclists per day and any other measurement time interval.

In addition to directly counting the number of bicyclists, additional attributes could be evaluated, such as gender, age, availability of protection gear, category of the bicycle, rental or bike-share usage.

In order to increase safety requirements during the construction[5-8, 19] of the bicycle infrastructure, it is planned to reduce the speed of automobile flows in the places of interfacing with bicycle paths, as well as the separation of automobile and bicycle transport by building isolated bicycle paths. It is also necessary to discuss with the cycling community the necessity to comply with traffic rules and safety standards.
For a metropolis, it is very important that the bicycle infrastructure is not simply covering the large territories but also provides connections with the city transport infrastructure (public transport stops, subway stations and commuter trains), as well as with the city’s points-of-interest - recreation parks, educational institutions, shopping centers, museums, and business centers. The need for connection with urban transport infrastructure is due to the fact that bikes can be used to get to the desired public transport route.

Directness is considered both in terms of the presence/absence of obstacles along routes, and the ability to choose the desired route - the most acceptable from the position of minimizing possible obstacles. Analysis of foreign literature [17] revealed such indicators of directness as the delay time at traffic lights or the estimation of the elongation factor: the ratio of the distance between points of a bicycle route in real conditions to the length of the user's path between these points in a straight line. However, in the study there are no “hard” indicators because their assessment is possible using only panel studies since the use of questionnaires not provide the desired accuracy of the data.

The personal security of bicyclists and the safety of their personal property are among the critical demotivating factors for the bike-users. If the townspeople doubt the security of riding a bike, then it ceases to be attractive. The level of user awareness should also be assessed in the “attractiveness” category because user needs to know the location of bike rental points, bike parking, and route lengths.

The willingness of citizens to use bicycles is influenced to a large extent by the comfort indicators such as the ability to experience smooth and relaxed cycling without excessive physical and moral stress. To make routes more comfortable, a search for new technological and design solutions based on the results of monitoring the use of urban infrastructure is necessary. The indicators that form the basis of the monitoring system are presented in the table:

| Table 1. The system of indicators for monitoring the development of cycling infrastructure |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Indicator | Characteristic | Payment | Data source |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1. Intensity | The number of bicyclists traveling at at point of measurement per unit time (per day or one hour) | Intensity = Vehicles number per time unit | observation at intensity metering points |
| 2. Security | Basic requirement for the development of urban cycling | Rate of accident = \( \frac{\text{Number of accidents with bicyclists}}{\text{Total number of accidents (in the city or the district)}} \) | Statistics of the Ministry of Internal Affairs, poll |
| | | Cycling infrastructure security index = \( \frac{\text{Secure bicycle tracks share}}{\text{Total bicycle tracks length}} \) | |
| | | Perceived safety level = \( \frac{\text{Number of respondents who evaluated cycling infrastructure as safe}}{\text{Number of respondents}} \) | |
| 3. Cycle routes cohesion | The ability of bicyclists to move from the starting point to the point that is the goal of their trip | Density of cycling infrastructure = \( \frac{\text{Total bicycle tracks length}}{\text{Area square}} \) | Data of city structures, calculation, survey |
| | | Cohesion index POI = \( \frac{\text{Number of POIs linked to bicycle infrastructure}}{\text{Number of POIs}} \) | |
| | | Cohesion index TP = \( \frac{\text{Number of transit point linked to bicycle infrastructure}}{\text{Number of transit points}} \), where Transit points are the urban transport infrastructure facilities | |
| 4. Directness | Provides bicyclists the shortest possible connection without factors increasing the number of dismounts | Perceived Directness level = \frac{\text{Number of respondents who evaluated cycling infrastructure as direct}}{\text{Number of respondents}} |
| 5. Attractiveness | Reflects the conformity of bicycle infrastructure to the needs and expectations of traffic participants | Perceived attractiveness level = \frac{\text{Number of respondents who evaluated cycling infrastructure as attractive}}{\text{Number of respondents}} |
| | | Perceived level of information richness = \frac{\text{Number of respondents who evaluated cycling infrastructure as informationally rich}}{\text{Number of respondents}} |
| 6. Comfort | Reflects the possibility of cycling with a minimum amount of physical and emotional effort | Perceived level of comfort = \frac{\text{Number of respondents who evaluated cycling infrastructure as convenient}}{\text{Number of respondents}} |

The presented system of indicators did not receive weight coefficients at the testing stage; however, their use with the accumulation of data is not excluded. Safety indicators will remain a priority, “attractiveness” will receive the highest value for recreational purposes, and “connectivity” for routes with a utilitarian purpose.

4. Discussions
The proposed indicators for monitoring the development of bicycle infrastructure include both “hard” and “soft” indicators. “Hard” indicators can be determined by counting and measuring, assessing compliance with the norms and rules of the regulatory framework. “Soft” indicators are estimated based on the results of the survey and observations and allow reflecting qualitative changes.

When forming the indicators system structure and its content, the task was to ensure a compromise between the interests of all participants in the movement and to exclude discrimination of individual groups of the population. The work also determined the source of obtaining data on monitoring indicators from administrative or other structures. This solution allows localization of responsibility for fulfilling the quality requirements for bicycle infrastructure.

Evaluation of the bicycle infrastructure characteristics according to the proposed indicators can be carried out at the level of the entire route network or specific bicycle routes and their parts (traffic interchanges, intersections, designated sections for the joint movement of public transport and bicyclists, etc.), as well as bicycle infrastructure (parking lots, rental points, repair shops, etc.).

Additionally, assessment indicators may be included in the monitoring system that characterizes the level of the influence of bicycle infrastructure on the quality of life in a city, on the economy of a metropolis, the health status of citizens, the city’s ecology, and the transport environment.

An analysis of international experience has shown that a high-quality network of bike paths fully integrated into the urban and municipal transport infrastructure can be created in 10–15 years [18]. Currently, the development of bicycle transport in the city corresponds to the first level of maturity [18]. It means that the need for solving the problems of local development of bicycle infrastructure...
infrastructure integrated into the transport infrastructure of the city for the possibility of multimodal trips.

The proposed structure of the indicator system is based on the allocation of groups of indicators according to the most important characteristics of the research object. This structure allows identifying a problem area (for example, comfort, safety, cohesion) with details of the causes of a problem (for example, the lack of infrastructure facilities at different stages of the bicyclist route). If the goal is achieved, a group of indicators can be excluded from the monitoring system without violating the integrity of the system.

Besides, the proposed system of indicators can be applied when changing the monitoring objectives or scale (for example, not on a city scale, but also on a regional scale).

The indicators proposed for evaluating the monitoring system were primarily aimed at achieving the goals at the initial level of bicycle transport development in the metropolis: increasing the mobility of citizens. However, they are designed in such a way (hierarchical system) that allows to assess the achievement of goals emerged at the second level, which includes the development of bicycle infrastructure, increased physical activity, changes in the transport behavior of city residents, planning the development of bicycle infrastructure, increasing the effect of the development of bicycle transport infrastructure.

Thus, the proposed indicators for monitoring the development of urban bicycle transport infrastructure make it possible to provide a flexible approach to assessing indicators at various levels of management and shift the focus of development depending on the achievement of components of goals at various levels.

5. Conclusion

The indicators proposed in the study allow to assess the development level of bicycle transport infrastructure at various levels, to identify changes in the transport behavior of citizens using bicycles, to determine the most promising options for planning bicycle infrastructure. Traffic intensity, safety, cohesion, directness, attractiveness and comfort are those indicators that form the basis for subsequent changes in the transport bicycle infrastructure of the city.

At the initial stage, monitoring objectives are defined: a flexible system of proposed indicators allows us to shift the focus to the most relevant indicators in the current moment of the urban environment development. At subsequent stages, a system of criteria and indicators for their evaluation, and a system of target indicators are formed, on the basis of which a comparative analysis of the results achieved with the goals is carried out.

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