

Main directions of sustainable development of transport systems of major cities and agglomerations

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Abstract. This article considers the main directions of sustainable development of transport systems of major cities and urban agglomerations. The authors notice the factors affecting the operation of transport systems, formation and redistribution of transport flows. The work analyzes conditions for ensuring interaction between different modes of transport in different urban planning conditions. This article indicates the features and prospects of wide use of public transport. In this work characteristics of the development of transport systems of urban agglomerations are indicated, including in conditions of repackaging of urban areas. The authors define the measures necessary for the improvement of transport framework of agglomerations and formation of intermodal transport system.

1. Introduction

The sustainable development of urban areas includes not only the resource balance of individual territories and functions, but also effective provision of their interaction in conditions of continuous development and changing urban parameters. Urban development changes the operation of transport systems and requires their constant adjustment, including transport framework structures and transport management systems. The compaction of urban environment requires adaptation of the street-road network and modernization of transport nodes. The importance of transport as a branch of the economy is such that designers have the task not so much to react to changes in the urban structure as to anticipate them and take this into account in the design of transport systems.

Sustainable urban transport development is now linked to key interlinked characteristics such as environmental sustainability, energy efficiency and resource balance.

The evolution of "green transport" implies minimizing the environmental impact of transport. In this context, improvements in transport systems may include reducing or eliminating harmful emissions from the operation of ICE into the atmosphere; reduction of noise generated during operation of vehicles; Improving traffic safety; changing the quantity and quality of transport infrastructure to reduce its share in the balance sheet of the city; improving the video ecology of urban transport systems.

The efficiency of transport can be characterized by the number of different urban resources spent on transport of one passenger. These resources include both the direct financial costs of carrying passengers by public transport, establishment and maintenance of transport infrastructure and costs of diverting territory for transport.



2. Materials and methods

The development of the transport system of modern cities by extensive methods seems unproductive already because at high densities of development of territories, as a rule, there is simply no space for accommodation of additional transport infrastructure. The intensive development of systems implies an increase in the capacity of transport communications by increasing the speed of flow, or the density of flow per unit area. The solution is the arrangement of multi-level off-street transport lines isolated from local street traffic, which provide high speed of movement on one side, and increase of passenger capacity of vehicles, which can only provide public transport.

There are currently two main models of urban public transport operation, differing in the type of management of the urban passenger transport system. The first "market" system is most common in developing countries and involves, in practice, sale of passenger concessions to third-party carriers. In this case, all concerns about maintenance of personnel and rolling stock, as well as financial risks fall on shoulders of these organizations, which in turn build work on selection of a fleet of vehicles and formation of a schedule for its operation on routes, based on commercial expediency. With obvious financial advantages of such an approach, which excludes the content of grant urban transport for the municipal budget, there are significant disadvantages: minimization of own expenses by carriers negatively affects the quality of services provided by them and the safety of passengers, and such a business model itself does not involve long-term investments and is based on maximizing benefits in the short term. However, the most problematic issue is the lack of coordination among the various carriers in the context of a common transport system. Another model, common in cities and urban agglomerations of developed countries, is based on subordination of carriers to a centralized (state or municipal) structure, which, as a customer of transport, enters into contracts with operators serving all lines of urban transport. Service charges received by operators consist of compensation for their costs (transportation costs) and fixed profits, and thus the management structure takes on the financial risks of individual carriers. This approach makes it possible to improve transport safety, the quality of passenger service and to streamline travel fees, as it is regulated centrally by municipalities. However, the most important advantage of such a model is the possibility of providing the management structure with centralized information support for operators, monitoring and management of the common transport system. Centralized systems management is particularly important in the context of major cities and agglomerations. These areas tend to have fairly large linear dimensions, as well as a variety of functional and planning structures, which involves the use of multilevel transport systems that include both personal and different modes of public transport.

Modern cities typically have a multi-level public transport system. On the first level there is urban transport of local importance, which serves for communication inside and between districts of a city. Such transport moves on a common street-road network, and its stops of its developed route network are in pedestrian accessibility. The large number of stops and street crossings on the route make it the slowest. Off-site public transport links remote areas of cities, public centers of transport and transfer nodes of external transport, etc. The absence of intersections with city streets allows increasing the speed of movement, but it is also advisable to reduce the number of stop points. The use of special engineering infrastructure (bridges, tunnels, trestles, embankment) significantly increases the cost of construction and does not always allow achieving the necessary density of the network. In some cases it is possible to use high-speed street transport, but single-level intersections with other transport links significantly reduce the average speed of its traffic. Suburban transport links the core of the agglomeration to its peripheral zones. Transfer points of external and urban transport are often used as nodes, and links are both dedicated routes and public highways. External transport does not participate in intra-agglomeration connections, but nevertheless affects the structure of agglomeration and the city and internal communications through the peculiarities of tracing highways and the location of transport and transfer nodes.

Historically, urban transport communications were located at the ground level, but the processes of repackaging urban fabric coincided with the industrial revolution, which gave a powerful impetus to development of new modes of transport and transport infrastructure. The result was the emergence in

the mid-19th century of off-street passenger transport, the highways of which are located below the ground level (London Underground) or above the ground (New York Metro). Currently, such highways are widely used in major cities for various modes of transport. All three types of tracing have their advantages and disadvantages. Land highways are relatively inexpensive, but cut the city, making communication difficult. Above-ground roads require trestle arrangements and disrupt the city's visual environment, but provide high speed traffic without intersecting city streets in the same level. Underground extremely expensive in construction, but do not disrupt an image of the city, they are protected from precipitation and allow improving the environmental situation by the possibility to isolate noise and exhaust of internal combustion engines. Multilevel schemes that combine multiple types of trunk tracing are of particular interest. Multilevel highways allow a more rational approach to the use of urban areas, increasing the density of traffic flows per unit area. In part, such solutions were embodied in New York City (Trans-Manhattan Expressway), Philadelphia (Vine Street Expressway), Munich (E54 highway in Tegemseer Landstraße). In these examples, multi-level highways allow the separation of different value (transit and local) flows and are a combination of partially buried and urban street-level sections. The principle of "multi-level street" is taken as the basis for designers of integrated transport corridors in economically developed Asian megacities. In Singapore, such a two-level corridor with an open ground part should link the north and south of the island [1], and in South Korea multilevel tunnels are supposed to be laid below the metro level, and they can serve even to connect cities [2].

Based on the fact that with development of urban agglomeration areas more and more trips are carried out using several modes of transport, it can be argued that efficiency of the transport system of the city depends directly on the coordinated interaction of all its subsystems. Thus, intermodality becomes one of the most important parameters of modern transport.

The Federal States of Germany control transport operations through organizations acting as a single customer. For example, the Rhine-Ruhr Transport Association (VRR) plans and coordinates the passenger transport system of one of the largest Rhine-Ruhr Conurbation in Europe, also responsible for tariffs, electronic payment systems and control of transport processes through its own security service. Under the management of the association there are more than 1000 routes, including intercity trains, metrotram lines, bus, tram, trolleybus, monorail. At the same time VRR manages the operation not only of carriers of local level, but also, for example, of the regional branch of the main railway operator of Germany Deutsche Bahn [3]. The created control system allows using a single ticket (including electronic) on the whole route regardless of the number of transfers and operators and coordinating the time and place of docking depending on the load of lines. The use of electronic ticket sales systems also makes it possible to predict the loading of passenger routes.

The development and implementation of intelligent transport systems that enable the collection, processing and provision of information to improve traffic safety and facilitate the timely redistribution of traffic when difficulties arise at different sites play an important role in optimizing urban traffic. Such systems inform the traffic participants of the state of the situation with the system by means of external or internal devices. Their work allows them tracking traffic and responding to its evolution or changing conditions. However, the main problem with optimization of transport systems is the forecast of the situation. For route vehicles, such a forecast can be made with a sufficiently high degree of accuracy, but the forecast of the movement of private vehicles can be made only on the basis of statistics that can not take into account spontaneous changes in the situation in the system. In this case, the use of an "application" mode of movement, in which drivers of non-routine transport declare their intention to travel, obtaining from the system the optimal route checked with other "applicants," while booking the necessary parking space, seems promising. Such a regime can be applied locally in urban zones of increased activity, for example, in historical centers of cities, but in order to obtain a qualitative result it is necessary to use in large transport systems.

In the 20th century, one of the leaders of the world economy was the automobile industry, which produces one of the most demanded goods, and stimulates development of a large number of related industries: metallurgy, chemical and petrochemical production, electronics, etc. A car, due to its

relative compactness, mass content, freedom of route choice and comparative ease of operation, became one of the main vehicles in urban conditions. The first half of the 20th century was marked by development and popularization of urban planning theories representing a "city for a car," in which the function of the main passenger transport is performed by personal vehicles. However, active motorization in highly urbanized areas against the background of insufficient capacity of highways gradually resulted in difficulty of transport communication in cities and agglomerations. This determined the emergence of alternative concepts of transport development, in which the main carrier was already public transport, and ideally all their needs are met in the walking distance zone [4,5].

Nowadays the theory of urban transport has developed a steady perception that the main means of transportation of passengers is public transport, the use of which is actively stimulated, including by restrictive measures imposed on private vehicles. This approach implies that urban transport infrastructure should be reoriented towards using of public transport. Dedicated lanes, transfer nodes, etc. are organized for it. If it is possible, personal transport is excluded from overloaded areas by creating uncomfortable conditions of use (prohibition, restriction or payment for entry, parking, etc.). Restrictive measures generally affect historical centers of highly urbanized cities and territories. Naturally, such measures are effective only with a developed system of affordable public transport, and a deliberate intermodal approach to formation of a transport system [6,7]. A classic example of this approach is reconstruction of Munich transport system, when restrictive measures for motor vehicles in the historic centre were an addition to arrangement of convenient communication for S-Bahn trains. In fact, passengers from the suburbs have the opportunity to reach the central square of Marienplatz without resorting to transplants, which significantly increases the comfort level [8,9]. There is a large transport and transfer hub serving two metro lines and seven commuter-city train lines under the square. At the same time, the central part of the city is not completely closed for cars, and there is a relatively developed infrastructure of public parking. There are also intercepting parking arranged on the border of the central zone. Another example is the situation in central London. The introduction of toll entry to central areas for cars in 2003 was one of the most famous examples of traffic restriction in the modern major city. Entering the paid area during working hours costs £11.5 (a £1 discount if the payer is registered in the system), and residents pay only 10% of the amount. The London Toll Entry Project is managed by Transport for London Corporation (TfL), which manages London transport system, including public transport. It should be noted that despite the high entry fee, traffic has decreased by not too significant 10-15% compared to the "free" period, although the TfL states that the overall balance of the vehicle fleet entering the zone has been redistributed towards public transport, which is not charged. According to TfL, the situation with congestion during "rush hours" has not changed much, and not always for the better. The project itself proved to be very profitable and generated about £250 million in 2017, with operating and administrative costs of about £86 million. According to the law, profit received should be directed to development of transport infrastructure in London [10].

Similar traffic restriction schemes are applied in many cities around the world, including Oslo, Stockholm, Singapore and Dubai. In some cases, there are no charges or discounts for entering the zones of electric vehicles, hybrid vehicles or vehicles with low concentrations of pollutants in exhaust.

An alternative to paid entry is the option of prohibiting traffic in special areas of private vehicles not owned by residents. Such restrictions are often imposed in the historical centers of cities with a shallow planning structure and a significant flow of tourists, such as Zona a traffico limitato (ZTL) in Italian cities such as Rome, Bologna, Florence, etc.

In many cities of the world, there is a tendency to deliberately reduce the number of parking spaces in public buildings and structures in order to encourage population to use public transport.

For all the apparent expediency of such measures, they also have some side effects. So the residents of a city can refuse to travel by car and use public transport for the necessary trip to work, but completely refuse to travel to the theater, restaurant or simply for a walk historical environment, preferring a large shopping center with a large parking lot and a variety of entertainment program.

Indirectly, this is said by the example of the center of London: with the general decrease in the traffic of private vehicles in the "paid" zone, the load on passenger transport has not increased significantly.

Urban street transport can be rail or trackless, both systems have their advantages and disadvantages, but do not have decisive advantages. Trackless vehicles generally have more freedom to trace routes, but are more tightly limited in size and do not support coupling work. Rail roads have greater capacity and acceptable maneuverability of composition provided by guiding tracks, but the same tracks severely limit flexibility in selection of routes and require specialized maintenance. In any case, the main advantage of public transport is its large passenger capacity per unit area occupied on the roadway, and as the size of the vehicle increases, this ratio becomes only higher. This forces city authorities to eliminate, as far as possible, interference with public transport in private vehicles in the face of a lack of space for large urban transport. However, such a scheme, with all visible advantages, also has some disadvantages. High passenger capacity is rational at maximum load during "rush hours," but with decreasing passenger traffic, efficiency and payback of transportation drops sharply. In fact, the payback of public transport is one sign of repackaging of modern cities. Only oversaturated with high-rise development and, accordingly, highly dense traffic Asian megacities (Hong Kong, Singapore, Tokyo, etc.), in which off-site transport becomes the only stable means of transport, boast of the profitability of this branch of urban economy. In fact, it is not the last condition of payback that transport systems of these cities are stably overloaded. Although this results in a decrease in comfort (in the Tokyo Metro, for example, there is an official position of "oshiya" - an employee pushing passengers into crowded cars), but in the absence of an actual alternative does not lead to the outflow of passengers from the system. In areas with particularly high density of development (areas of Central and West, East, Yau Tsim Mong, Sham Shui Po in Hong Kong, Shinjuku in Tokyo, etc.) stops of off-street transport are often located at intervals comparable to distances between stops of street transport of local (intra-district) traffic. Thus, it can be said that off-street transport, in some cases, not only duplicates, but also partly replaces street transport. Given that many experts consider the example of Asian megacities as the most likely vector of development of many of the largest cities around the world, it can be said that urban transport systems can develop on the same principle.

Due to uneven loading of public transport among specialists, there are different opinions about efficiency of allocating specialized lanes for its traffic: a large part of time this space is used irrationally, as neighboring lanes provide for movement of more passengers than a lane with underloaded public transport.

The situation is slightly different with urban off-site transport, represented in mass by its underground, monorail and suspended systems, and in some cases by railway lines. As a rule such solutions initially involve significant loading, high speed, relatively large intervals between stops, and serve not for local communication, but for communication between the areas of a city, and in some cases the suburbs. Tracing of tracks outside streets allows smoothing the trajectory as much as possible and, accordingly, increasing dimensions of vehicles, their capacity and speed of movement. In this case, dimensions of vehicles are linked to the structure of the city not directly, but through interaction with it by placing transport and transfer nodes and their permissible spatial characteristics along a route. The high passenger capacity of such transport results in the need for large transfer units capable of quickly serving large masses of passengers, which requires not only large-scale structures, but also communication spaces to redistribute pedestrian flows in front of them. In modern cities, implementation of such an approach is not always possible because of lack of territory or specific requirements for its rational use. One solution to this problem is to take maximum retention and redistribution of passenger flows directly within a transport node. The most striking examples of this approach are transport and transfer hubs in Hong Kong, originally designed not only as transport facilities, but also as large social and business centers [11,12]. In highly urbanized environment, this approach has a number of advantages over the conventional predominantly monofilament scheme of a transport hub. Firstly, communication between a transport hub and a community center is minimal in distance and does not require significant open urban space. In some cases, passengers do not even actually leave the boundaries of a transport facility. Secondly, the area of the hub receives a powerful

service center, and its residents have no need for additional movements around the city. Thirdly, management of non-core assets brings profit to the urban transport system and indirectly increases the payback of its work, as clearly evidenced by the Firebox recovery ratio index, which made 124% for the Hong Kong MTR system in 2016, which is one of the highest indicators in the world [13]. In general, in highly urbanized areas of Hong Kong subway stations are integrated with underground parts of public buildings and show little in the city structure above ground level. This reception is typical of "common" stations serving territories with "homogeneous" high-density development. Another approach can be presented in the form of structurally separated and visually identified complexes. Such solutions are used in areas of major points of attraction or crossing of main transport highways and are typical of multimodal transport hubs serving several modes of transport and requiring connection to existing or additional transport infrastructure. An operator not only offers to rent premises located directly in the concorts of the stations, but also owns an ever-expanding network of multifunctional public complexes with built-in transport facilities.

3. Conclusion

A feature of the work of transport systems is the seemingly paradoxical conclusion that the better the system works, the higher the load on it becomes. Indeed, development of transport encourages a person to make trips that he had not previously planned. In fact, the situation with the balance of the transport system is described by the Pigou-Knight-Downs paradox, about the direct dependence of the capacity of the links and load on them, and by the Lewis-Mogridge postulate that with the growth of the number of links and improvement of the transport situation, the number of vehicles gradually increases, and it leads a system to the initial state [14]. In addition, decrease in the speed of public transport leads to decrease in the speed of personal transport, due to transition of some passengers to using a car. Indirectly, this suggests that the problem of organizing the city transport links cannot be solved within the transport system. At the heart of any movement is a necessity, and one way to improve transport comfort is to satisfy the needs with optimal use of transport. At the current stage of technology development, many tasks do not require the physical movement of a person around the city. With the help of electronic networks it is possible to get information, choose and order delivery of goods, read books, watch films and listen to music without visiting shops and even to work. Thus, it is possible to speak about formation of a new image of the city in which people are not so strongly tied to administrative centers and service enterprises.

Based on modern realities, it is possible to formulate the basic principles of sustainable transport development in the modern city:

1. The environmental friendliness of transport development is not only to reduce emissions, but also to balance "space for people" and "space for cars." Extensive methods of transport systems development have no place in urban development plans.
2. Urban transport should have a control centre that coordinates different modes of transport and sets service standards within the overall transport system.
3. Intelligent transport management systems should be introduced to inform traffic participants and predict evolution of traffic flows.
4. There is no ideal mode of transport. Public and personal transport performs their part of the overall task. Both have pros and cons, but cannot completely replace each other, and it is necessary to find a balance between them. Restrictions imposed on the operation of one mode of transport are not an ideal tool and can lead to side effects.
5. In a complex modern city there can be no simple transport system. The larger the city, the more complicated and multilayer its transport frame.
6. The transport infrastructure of a modern city is not a separate element of the urban structure. Urban transport structures can and should be integrated into the functional fabric of a city.

Speaking about the problems of transport in cities, it should be understood that most of them are the result of mistakes of urban planning, incorrect zoning and repackaging of the territory. Urban

transport is a complex multi-level system, involving integrated planning and clear coordination of all its elements.

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