

Leading Potential for the Intensive Development of a City

Alexander Paraskevov*

Federal State Budgetary Educational Institution of Higher Education
 “Kuban State Agrarian University named after I. T. Trubilin”
 Kalinina str. 13, 350044 Krasnodar
 Russian Federation
 e-mail: paraskevov.alexander@yandex.ru

Anna Chemarina

Federal State Budgetary Educational Institution of Higher Education
 “Kuban State Agrarian University named after I. T. Trubilin”
 Kalinina str. 13, 350044 Krasnodar
 Russian Federation
 e-mail: lyasenkoa@mail.ru

Abstract Common principles and rules for urban development have almost never existed. The way (in a geometric sense) a settlement should be depends on many disparate factors. The landscape component, transport factor, and resource factor play a role. When there are natural barriers (forests, mountains), it has long been much more convenient for people to arrange their home in flatter part. The presence of rivers has always attracted residents – it is both a source of food and an important transport hub where there is always a possibility to be hired. Mining areas were built around the source of resources and, of course, employment. Almost never has urbanization been based on the principle of transport planning. Such cases are isolated and only confirm the general trend. Urban infrastructure is a dynamically developing and changing object. The extensive development path involves expanding the existing boundaries of the urban agglomeration, i.e., developing "in breadth". Intensive, in its essence, is the use of technological progress, the improvement of existing facilities, the use of technical progress for development. The extensive method may be less effective, but sometimes it is one of the important areas of development, without which further intensive development cannot carry on.

One of the most pressing problems that can be partially solved using an extensive method of city development is the problem of congestion of the transport system. The expansion of the city implies the expansion of roadways, and as a result, a reduction in the load and distribution of traffic flows on the road network. Our paper focuses on these issues and studies them thoroughly.

Keywords: *urban development, traffic flows, road network, smart cities, leadership*

1 Introduction

Imagine a road as a strip of land that is equipped or adapted so it can be used for the process of movement of vehicles, or it can also be an artificial structure surface. It includes one or more roadways, as well as tram tracks, sidewalks (possibly with lawns), curbs and dividing lanes, if any. If we consider the number of directions of traffic, there are one-way and two-way roads; the number of lanes for traffic makes it one-lane, two-lane or three-lane (having more lanes is also possible) (see e.g. Loiko and Paraskevov 2010).

The variety of modern technologies application for traffic management and statistical data collection is striking. The methods of using balloons and helicopters, TV cameras and aircraft (drones) when "patrolling" transport infrastructure objects are already out-of-date. Currently, the data received from mobile towers is the most relevant (Lai et al. 2019). This is information about the number of operators, their movement from cell to cell, and the speed of movement. If we consider the size of mobile operators' cells (in cities this indicator has a radius of less than 1 km), we have to consider this data very reliable (Xu et al. 2019; or Guzman et al. 2020). This also takes into account geolocation enabled on many mobile devices. Each of the solutions has its own positive and negative sides. They surely have one thing in common – a long payback period. The technical implementation of such solutions is quite complex, and the legal side of the issue (the use of such data is on the shaky line between the concepts of "personal data" and "surveillance"), in turn, is influenced by the territorial and legislative affiliation of the place of application (Strielkowski et al. 2020). In some countries, laws allow the collection and processing of this information, in some it may be done only with the permission of citizens, and in others it is absolutely prohibited.

The city's urban road infrastructure has been subjected to more and more congestion every month over the past few years. The number of city residents increases from month to month due to migration of residents from other regions. The rapidly growing number of residents of surrounding localities working within the city limits also plays an important role here. They create traffic every day at the entrances and exits of the city, respectively. The quantity and "quality" of vehicles plying within the city limits does not allow 6 days out of 7 (including Saturday) to increase its number by another 100-150 thousand units. In this issue, we should also mention the transit traffic flow, which in its vast majority passes through the city, and not in a detour (Malecki et al. 2014; Paraskevov and Ivanenko 2019).

The transport system has been developed in stages and has been always greatly influenced by wars. Highways are usually used for rapid movement of troops. This is a time of very high balance between the speed of construction and the quality of the final product.

High-quality transport routes are profitable for everyone, and the authorities are trying to fix the situation by all means: natural road duty, mandatory work, various taxation systems, prison labor, and so on. Sometimes, despite the illiterate general management of the road work, the state manages to put great amounts of kilometers of profiled dirt and paved roads into operation.

The object of research is traffic management. The subject is improving traffic management based on the use of mathematical and instrumental methods of economics (see e.g. Takhumova et al. 2018a; or Takhumova et al. 2018b). The theoretical and methodological basis of the research is the development of domestic and foreign scientists, economists and mathematicians in the field of system analysis, decision theory, management theory, economic and mathematical modeling and analysis, information systems design. The research uses the following theoretical methods: control theory methods, multi-criteria optimization methods, mathematical programming methods, simulation methods, queuing theory methods.

2. Methodology and research design

In the current situation, the direction of development of the entire transport infrastructure of the city should be carried out only by developing an initial comprehensive transport scheme. It should take into account both cargo and passenger traffic throughout the city. And in the context of this development, it is certainly necessary to immediately consider suburban satellite towns, the number, quality and direction of roads there. Without improving these facilities, there will be no solution to the problem. All traffic jams will be simply moved for a few kilometers, and it is quite possible that they will lengthen over several years. A comprehensive traffic management scheme should contain a crossing over railway lines that literally divide the city into several parts and create a bottleneck effect, in which residents are trapped during rush hour of the transport infrastructure (Filatov et al. 2018).

The development of traffic management projects on non-working days and holidays is also a key point due to the fact that on these days, as a rule, the main street is closed to all the traffic and it is possible to cross it only in 3-5 places, which is unacceptable with the current load on the transport infrastructure and runs counter to the tasks of optimizing the entire transport network.

According to international building codes, the roadway that is being put into operation (considered as part of a common street network) must be designated in all guidance documents as part of a common network, and keep information about the sections of the SRN (Streets and Roads Network) that share arcs with it. We also need to comment on the rationality of the overall planning and development of the transport network.

We use a special parameter to determine the quality and condition of traffic on the street. According to this parameter, it is possible to determine the necessary impacts on the site; the parameter defines a transport characteristic that determines the traffic conditions on the SRN site and regulates measures to influence changes in traffic conditions using design measures and traffic management tools.

It is planned to differentiate street sections by purpose and transport characteristics for each geographical zone in accordance with the recommended values of the indicator:

- for zone A—all SRN sections have LOS=3 or 4;
- for zone B—all SRN sections have LOS = 2, 3 or 4;
- for zone C – all SRN sections have LOS=1 or 2.

The essence of the indicator coefficients:

1—streets with the maximum load level and restricted access to adjacent territories. They are typical for an area with a large number of warehouses and industrial facilities.

The main function is transit traffic, high traffic intensity, a large number of trucks and long-distance trips of all types of transport. Access to the surrounding areas is restricted. Parking is prohibited. Stops for non-rail transport-only on special lanes.

2– SRN section with priority of service level before access to territories.

3– SRN section with priority of access to territories before the service level.

It combines the functions of transit traffic and the functions of servicing adjacent territories, as well as the separation of street users in space and time (cars and public transport, pedestrians and bicyclists).

4– SRN section with maximum access to territories, with a low level of service.

3. Results and discussion

Program-oriented planning is necessary for the organization of transport infrastructure in new urban areas that are being created. It is impossible to imagine such areas with very dense development and an incredibly small number of parking spaces, two-lane streets, lack of modern roadbed and chaotic operation of traffic lights. But these are precisely the neighborhoods that currently require maximum attention.

Using the three-level zoning model for urban areas helps us identify areas that need to be improved. At the moment, a common division is based on the distance of objects from the city center. In this case, it is customary to allocate three groups of objects. The first group consists of urban infrastructure objects and territories that belong to the central part of the city. As a rule, these are objects of cultural and historical heritage, administrations of administrative divisions, park zones and a few office buildings.

We have conducted aresearch for ways to reorganize traffic in a modern city to find more effective traffic management strategies than existing ones. Any decision to change the road traffic must be scientifically justified and have an evidence base – mathematical apparatus and the results of numerical experiments. Making unwarranted decisions leads to a high risk of collapse. It is necessary to understand that the management of socio-economic objects has an impact both on the economy of the region and on the people's lives.

The second group includes residential areas and residential areas. They are characterized by the presence of a large number of apartment buildings, shopping centers, an extremely small number of parking spaces (according to preliminary estimates, the availability of parking spaces and garages is about 35-40%), roadways that are not designed for the existing flow. It is this particular group of objects that has same traffic jams occurred, which over time begin to spread throughout the street infrastructure, paralyzing traffic.

The third group of objects are usually referred to the peripheral areas. These are the territories of industrial facilities located within the city limits. Here, the main problem is heavy-duty transport running between cities. Mainline trucks must be unloaded outside the city limits, and cargo is delivered to the city using small trucks with a load capacity of up to 1.5 tons. A heavy-duty vehicle inside the city is clumsy, often using several lanes for turning (large dimensions lead to the fact that they literally "cut" corners). They are prevented from moving in the flow of city cars by very large "dead zones". These are areas around the vehicle where the driver does not see what is happening.

Using toll road facilities within the city limits will be able to redistribute the flow of vehicles within the city. To determine the amount of payment and the need for its introduction, a mathematical calculation model is used. Of course, economic measures alone are not enough. The measures should be comprehensive. Everything is being done to ensure that the traffic flow that occurs during the working week does not paralyze traffic on the streets of the city, but evenly loads them. This is why it is proposed to introduce restrictions. It is also important to take into account the presence of a factor of maximum permissible environmental load on transport infrastructure. They must not exceed acceptable standards. Their main task is to create such conditions that the traffic flow is redistributed throughout the road network, so that its loading is as uniform as possible. After all, it is the redistribution of flows that will reduce the load on those parts of the network where it is excessive and leads to congestion.

The demand for each departure-arrival segment (D-A) is described as a function of the total cost of the trip. If there is no fee, the maximum possible demand leads to congestion and queues on the busiest sections of the city's transport network.

To regulate the number of vehicles on a section of the road chain, we must first formulate restrictions. They are determined by the very factor of the availability of traffic flow, the capacity of the road network section. The target function can be different, depending on the goal. This can include maximizing traffic flow, increasing the smoothness of traffic, maximizing cash flow, and others. From the point of view of management, the socio-economic target function can still be seen to increase the smoothness of movement. Let's proceed to the equation of limiting the capacity of a section of the street road network.

In the system of equations (1):

(1-1) – a necessary condition for the demand constraints;

- (1-2) – condition for the presence of traffic flow in the network;
- (1-3) – physically, the traffic flow is limited by its maximum capacity;
- (1-4) – condition for the nonnegativity of the transport stream;

$$\left\{ \begin{array}{l} \sum_{r \in R} f_r = d_w (1 - 1) \\ \sum_{r \in R} f_r \delta_{ar} = v_a (1 - 2) \\ v_a \leq C_a (1 - 3) \\ f_r \geq 0 (1 - 4) \end{array} \right. \quad (1)$$

Variables:

- w – segment of the transport arc of the city road network;
- a – arc;
- r – route;
- d_w – demand on the D-A segment (the number of vehicles that intend to travel along the arc/segment within 1 hour);
- v_a – traffic flow on the arc $a \in A$ (number of cars/1 hour);
- V – is the vector of all flows arc;
- f_r – traffic flow on route r (number of transport / 1 hour);
- λ_a – percentage of transport reallocated to bypass traffic;
- $D_w^{-1}(d_w)$ – inverse value of the demand function;
- C_a – capacity of the arc a (number of vehicles / 1 hour);
- A – multiple arcs of the transport network;
- W – a set of line segments in the transport network;
- R – many routes;
- $\delta_{ar} = 1$, if the route is used on segment a , otherwise $\delta_{ar} = 0$.

Shown below is a system of equations and inequalities that "manage" the demand for a section of the transport network. The demand is elastic in this case. The point is to evenly distribute the entire traffic flow along the arcs of the street road network.

$$\left\{ \begin{array}{l} \sum_{a \in A} c_a \delta_{ar} + \sum_{a \in A} \lambda_a \delta_{ar} = c_w \\ \sum_{a \in A} c_a \delta_{ar} + \sum_{a \in A} \lambda_a \delta_{ar} \geq c_w \end{array} \right., \text{ at} \quad (2)$$

$$\left\{ \begin{array}{l} f_r > 0 \\ f_r = 0 \end{array} \right. , \text{ where } r \in R \text{ and } w \in W \quad (3)$$

$$\left\{ \begin{array}{l} D_w^{-1}(d_w) \leq c_w \\ D_w^{-1}(d_w) = c_w \end{array} \right. , \text{ at } \left\{ \begin{array}{l} d_w = 0 \\ d_w > 0 \end{array} \right. , \text{ where } w \in W \quad (4)$$

$$\left\{ \begin{array}{l} \lambda_a = 0 \\ \lambda_a \geq 0 \end{array} \right. , \text{ at } \left\{ \begin{array}{l} v_a < c_a \\ v_a = c_a \end{array} \right. , \text{ where } a \in A \quad (5)$$

Because of the limitations in formulas 2-5, we can make several conclusions:

1) v vector of all the flows of the arc a is considered as the direction of the flow to a particular arc. In this case it closely correlates with the capacity of the arc;

2) λ_a (at $a \in A$) - the degree of flow redirection on congested transport arcs is measured in relation to 0. This means, that when:

2.1) $\lambda_a = 0$ (there is no traffic jam on the road) $v_a < c_a$, therefore we can conclude that the road is free (there is no queue and the capacity limit $C_a = \max$ which leads to queuing is not reached);

2.2) $\lambda_a \geq 0$ (a certain part of the traffic flow bypasses, gradually creating a traffic jam), i.e., when $v_a = c_a$, then the distribution of queues (λ_a value) is positive when the capacity of the arc is equal to the traffic flow on the arc. To put it briefly, the number of vehicles on the transport arc is equal to or slightly less than the capacity;

2.3) $\lambda_a < 0$ (full-fledged traffic jam). Considering the bandwidth limit ($v_a \leq c_a$), it means that, mathematically, the value that reflects the redirection of cars in this case will be negative.

4. Conclusions

Overall, it becomes apparent that measures for the effective organization of urban traffic should be of an exclusively complex nature in order to create the leading potential for the development. There is no single cause for congestion, therefore solutions must be implemented together. The organization of high-quality road surface and adjustment of traffic lights in the "green wave" mode will not help in itself if the demand for trips exceeds the physical capacity limits of the transport chord. Priority measures are to determine the objects of urban zones that require technical improvement, as well as the connection of these territories with a sufficient and modern number of highways, establish transport infrastructure that requires improvement or creation, count the number and improve the quality and efficiency of connections between suburban localities and urban highways.

The most significant results are that we have improved a model for balancing the traffic flow of the urban network with elastic demand, in terms of introducing restrictions on the environmental load on sections of the street road network. In addition, we have adapted an algorithm for solving equations of the two-level fare introduction model (SAB).

Another value-added of our paper is that we have improved a model for calculating the main parameters of urban road congestion. Additionally, we have adapted a numerical model for calculating the main traffic indicators. The practical significance of the research consists in the possibility of direct use of improved methods, algorithms, architectures and software for functioning as part of the urban traffic management system. The method allows to increase the smoothness of traffic flow throughout the road network, and additional financial flows for the current repair and improvement elements of a road network.

All in all, the implementation of the results of modeling the introduction of tolls will remove all queues resulting from the overflow of the transport network. This should happen by replacing the downtime in traffic with an equivalent fare.

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