Traffic flow organization in urban transport transit hubs

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Abstract. Transport congestion problem on the city streets and arterial roads is one of the most argued ones in the world’s largest cities and agglomerations. The field of modern transportation solutions researches lies in the design of transport systems according to the smart city concept that consists in integration of transport planning solutions and intelligent technology. The article is devoted to the issue how to organize different types of transport flow in an urban transport transit hub as a centers of gravity and interconnection of human and traffic. The main aim of the study of basic roads and streets operation parameters on the example of transport transit hubs of the Moscow city is to develop an appropriate approach to roads and streets network planning, coordinated with traffic management rules. Such approach should be focused on the integration of modern requirements for territories design, for quality and safety of public spaces, and apply telecommunications and information technology. The first section in your paper.

Keywords: traffic flows, network of city streets, transport transit hub, elements of the graphs theory, streets network planning

1. Introduction

Explosive growth and transformation of Moscow agglomeration provides a strict necessity for development of smart technologies to supply optimal distribution of growing traffic flows, to enhance operation of all transport types and to create comfort urban environment. Hence, new objectives have been pointed out regarding city urban construction policy targeted on development and adoption of integrated system for reasonable and safe use of various city transport types and their interaction in order to satisfy different real-time transportation needs of population.

According to experience of foreign countries stable development of transport infrastructure is based first of all on public transport priority use and decrease of trips by individual vehicles [1]. However, none of public transportation means can satisfy population need in full; hence, transportation system has to include interconnected components, combining various public transport types as well as individual vehicles and pedestrian flow [2].

Interaction of different transport types is accomplished in transport transit hubs (TTH). TTH provision allows passengers to transit to other transport means and move within transportation network safely, quickly and conveniently; with this objective realized the necessary quality of transportation system is reached. A modern approach to solution of transportation system quality enhancement problem determines the implementation of smart-city principles where an integration of intelligent technologies with planning decisions is implemented [3].
The object of this article is a consideration of street-road network within TTH that plays a key role in it providing for due traffic within TTH territory, access to passenger transport points, parking lots and various-purpose facilities (Figure 1). For TTH’s optimal operation SRN has to distribute transition and non-transition transport flows as well as provide for service of different facilities. Major condition is a due coordination of its operation based on system-based transport flow distribution with minimum quantity of intersections [4].

Figure 1. Connection road network role in transport hub

Main quality factor that determines a load on a road is traffic intensity as estimated by SRN throughput rate.

Road network overload is characterized by loss of SRN throughput that leads to problems with public transport flow, rising danger in pedestrians’ traffic, deterioration of ecological situation, etc [5].

For Moscow, there is an actual problem of poor quality of existing planning decisions of transport hub that do not correspond to modern requirements for stable smart-city developments. The need for reconstruction of the most of Moscow TTHs determines the importance for scientific research in the field of SRN structure development in its territory as well as formalizing the principles and requirements targeted on search for efficient planning smart-decisions [6,7,8].

2. Method

The research is based on application of the Concept of traffic supply and demand estimation [9,10] as a methodological approach for the optimization of road network servicing transport hub territory. It allows to study the process of traffic flows formation and to understand how to control them. Supply and demand theory is widely used for analysis of transport services development in the process of transport planning. The classical four-step procedure allows determining assigned objectives that includes:

I. Trip Generation;
II. Trip Distribution;
III. Mode Choice;
IV. Traffic Assignment.

Let’s consider each of these steps according to road network operation a part of transport hub.

Trip generation determines by a number of services and infrastructure objects placed on the territory of a transport hub. All this objects form population demand and provoke traffic of transport vehicles with different aims:

- Speedy transit through transit hub;
- Transport flow to every facility;
- Short and long parking on parking lots of different function;
- Passenger vehicle or taxi drivers service passengers.
On this step it is necessary to determine different types of transport and traffic conditions. The aim is to understand what facilities need to be serviced by existing or projecting road network.

The next step is to comprehend *trip distribution* for every facility. It depends on particular design planning idea of composition of transport, engineering, public infrastructure as well as their location relatively to each other. Main idea is maximal separation of different traffic flows in order to make quantity of their intersection points as little as possible.

*Mode choice* for every road network element depends on conditions of transport services based on data obtained in previous steps. It becomes necessary to define the function of every part of roadway and access management to every facility, for example, as next:

1. Restrictions for any traffic in transport hub except for those rendering services to transport facilities: terminals, stop points, parking lots of different purposes;
2. Partial shifting of traffic flows to provide access to residence and public territories that are integrated to transport hub structure;
3. Fully allowed mixed traffic for all transportation.

The last step is *traffic assignment*. On this step it is necessary to determine such parameters for roadway that will satisfy the hole demands of its users or to provide only traffic corresponding to system capacity supply. So, to organize the effective operation of road network it is necessary to duly arrange its structure and provide throughput corresponding to demand within desired conditions of access to a transport hub facilities.

Implementation of this demand and supply theory into practice requires to apply analytic graph theory method. Graph theory is widely used for the choice of best decision in routing or designing of transport networks. It helps to reflect a structure of a transport hub, to determine traffic conditions and transport flow type and to define access condition to every roadway (fig.2).

Graph theory allows to interpret road network as a structure system that can be mathematically described using a set of certain parameters and allows to separate traffic flows and to propose the typology of roads in a transport hub.

From the graph theory point of view road network may be outlined as graph with multiple sections corresponding to nodes.

"Section" – is a physical section of SRN (traffic area), described by single set of physical parameters. Type of section is “branch” that is an oriented graph indicating a direction of flow with certain features. Several branches (flows) may go in one section, and branch can be located only within a single section.
“Node” – is a place of possible separation of vehicle traffic flows. Node is a peak of graph, describing the motion of traffic flow (fig.3).

All nodes have numbers from 1 to, i.e. V={1,…,N}; elements of multiple sections are pairs E = (i,j). [9] Nodes of a graph are infrastructural facilities of transport hub. For example, stop points, parking lots, facilities where user`s surge transport demand occurs.

| Graph sections                  | Graph nodes                                      |
|---------------------------------|--------------------------------------------------|
| ➢ Section length                | ➢ Traffic scheme                                 |
| ➢ geometric road way parameters (number of lanes, width in one direction); | ➢ Traffic control features;                      |
| ➢ Traffic intensity and flow composition | ➢ Geometrical parameters of intersection         |

Figure 3. Evaluated parameters of road network graph representation

Graph theory allows evaluating road network role in transport transit hub that reflects:
- Road network structure;
- Local function of every road section according to traffic intensity;
- Requirements and parameters traffic intersections;
- Input data about transport service for infrastructure objects in transport hub.

The information is required to provide access to the transport hub territory and its elements. Smart technologies are in this case the tool to access management located in the graph nodes including information technology, methods of intelligent motion control, etc. Graph theory allows not only to determine these points physically, but also to determine the device that allows to achieve a specific and reasonable goal of designing a transports node and ensure comfortable conditions of its use for the population in real time:
- Information about the current street network load;
- Intelligent passenger transport system
- Information on the availability of services and the possibility of their current use, for example, availability of parking spaces, rental point equipment, etc.
- Carsharing capabilities
- Information authorities about emergency situations
- Social services for the population
- Smart home efficiency technologies

Results of such analysis may be used not only for evaluation of existing operating conditions of transport hub but also as a base for evaluating of a project design decisions allowing to compare different alternatives of traffic organization to determine its optimal use.

3. Implementation

Present method was implemented on practice on the public transport transit hub Medvedkovo example. (Figure 4). It is located in North-Eastern Administrative district area of Moscow city and is serviced by the Kaluzhsko-Rizhskaja line of Moscow metro. This hub is located on intersection of collector (Shirokaya str.) and local (Grekova str.) streets. Also, there are 2 Park&Ride facilities with capacity of 163 parking lots, 6 bus stop fronts, 2 metro terminals and public trade area. Medvedkovo station is a terminal station used not only by city residents but also by people outside Moscow rural areas and towns and due to this fact the station is overloaded in morning and evening peak hours.

Existing passenger flow through this public hub is about 50 000 people per a day on 17 city buses, 17 suburban buses, 4 trolleys routes and metro station.
Figure 4. Transport flow in public transport transit hub “Medvedkovo”, Moscow

The Graph scheme of public transport transit hub “Medvedkovo” is presented on figure 5 and consists of:
1. Sections refer to main transport flows in the hub;
2. Sections refer to main pedestrian flow in the hub;
3. Nodes refer to bus stop points, metro station, Park&Ride facilities, public facilities.

Description parameters for each of the elements are numerical parameters such as the flow intensity and the traffic capacity of a section and the capacity of a node on the input and output passenger flow.

Figure 5. Evaluation of SRN operation at Medvedkovo hub using graph theory

Implementation of four-step model based on analysis transport and passenger’s behavior in this transport hub using graph theory allows developing optimal planning decision. Designed graph gives a clear vision of the hub structure and connections between different elements. The absence of duplicative sections, as well as the lack of a rerun inside the territory demonstrates the optimal organization of the hub.

Nodes of the hub graph structure present places of passenger transport demand generation. Sections are the ways that should provide safe, speedy and comfortable traffic between nodes and from outside the hub. As the result of the proceeding analysis we suggest to define optimal parameters of road and pedestrian ways according to the highest intensities of transit flows in every section using a number of criteria as follows in the table 1.

Results of such analysis applied to the transport transit hub Medvedkovo will allow to optimize its structure according to the existing passenger and transport demand and supply capacity.
4. Discussion
Public transport hubs design issues are among the most relevant in the practice of transport design. At present, a new regulatory document is expected, the task how to determine the required parameters of the elements of transport hubs becomes relevant. There is a discussion to introduce a system of access control to the road network, in particular in the transport hubs of cities. In any case, we are talking about how to use smart city technologies that will allow you to manage the process of traffic organizing to create high-quality public spaces. This work aims to develop this knowledge in the field of organization of the road network, including the use of smart technologies. The development of the proposed methodology has great potential for further development of traffic management in cities to solve transport problems.

| Evaluated indicator of graphs nodes and sections | Parameters of design solution |
|-------------------------------------------------|------------------------------|
| 1. transfer capability of road ways              | • geometric parameters of road ways; |
|                                                 | • types of intersections;     |
|                                                 | • traffic regulation.        |
| 2. transfer capability of parking lots           | • capacity of Park&Ride facilities |
|                                                 | • capacity of Kiss&Ride facilities |
| 3. transfer capability of pedestrian ways        | • geometric parameters of pedestrian ways connecting main hub nodes of minimum length. |
| 4. transfer capability of on-land public transport; | • geometric parameters of loading platforms; |
|                                                 | • required equipment.        |
| 5. transfer capability of off-land public transport | • geometric parameters of exits; |
|                                                 | • required equipment.        |
| 6. transfer capability of public areas           | • capacity of nearby parking facilities; |
|                                                 | • geometric parameters of a road and pedestrian ways. |

5. Results
- The application of the developed method lies in the areas of:
  - Create the structure of the road network in the design of transport hubs;
  - Set parameters that meet the need for node transport services;
  - Evaluate and compare different projects to make an informed choice of the best option;
  - Determine the use and composition of smart city technologies needed to manage a particular transport situation in a transport hub

6. Conclusion
The results of the research work are aimed at improving the transport situation with congestion in transport hubs. They are aimed at determining the vector of sustainable development of urban areas in the process of transport planning and design.

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References
[1] Danilina N Intermodal system for mobility demand in the realities of the Russian Federation: reality and forecast / E3S Web of Conferences 6:02001 2016
[2] Danilina N Vlasov D Development of "Park-and-Ride" system as a tool for sustainable access control managing. IOP Conference Series: Earth and Environmental Science, 90(1),012214, 2018

[3] Vlasov D, Danilina N, Shagimuratova A The Priority Directions of Public Transport Transit Hubs Development on Commuter Railways / Advances in intelligent systems and computing No 92, 2018, pp. 299-309

[4] Danilina N, Elistratov D Organization of municipal transport access control system. passenger service models / Transportation Research Procedia Čep. "12th International Conference "Organization and Traffic Safety Management in Large Cities" 2017.

[5] Muleev E Transport behavior of Russian population: sociological report Institute of transport economics and transport policy (High school of economics, Moscow) 2015

[6] Cools M, Fabbro Y & Bellemans, T. (2016). Free public transport: A socio-cognitive analysis / Transportation Research Part A: Policy and Practice 86: 96–107. 2012

[7] Fulda A S, Nimal E (2014). Node: Methodology for Energy Balance for a Transportation Hub and its Neighbourhood. In Transportation Research Procedia Vol.4:25–41 2016

[8] Calimante J (2012). Rail integrated communities in Tokyo. Journal of Transport and Land Use, 5(1). https://doi.org/10.5198/jtlu.v5i1.280

[9] Levashev A Application of geoinformation technologies for the transportation demand estimation Transportation Research Procedia 1:406-411 2017

[10] Levashev A G, Mikhailov A Yu, Golovnykh I M Modelling parking based trips / WIT Transactions on Ecology and the Environment. T. 2:1067 2013.