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The transport model as a necessary condition for the construction of an efficient transport system

El modelo de transporte como condición necesaria para la construcción de un sistema de transporte eficiente

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Content

ABSTRACT:

El complejo de transporte es un contribuyente importante al PIB de muchos The transport complex is an important contributor to the GDP of many developing countries. However, not all modern transport models meet the requirements of the modern society. Thus, the purpose of this study is to consider several technologies that aim to improve the organizational and economic mechanisms of the development of the transport industry in the Republic of Kazakhstan. The authors examined the potential transport accessibility of the most in-demand routes, with a view to creating a universal model of transport infrastructure optimization. The transport model of Astana was elaborated using methods of mathematical modeling. The practical value of this research is that policy makers can use its results to optimize transport flows and avoid additional transport costs.
Keywords: infrastructure, transport model, organizational and economic mechanisms of transport technologies, entropic approach, Astana, Republic of Kazakhstan.

RESUMEN:

El complejo de transporte es un contribuyente importante al PIB de muchos países en desarrollo. Sin embargo, no todos los modelos de transporte modernos satisfacen los requisitos de la sociedad moderna. Así, el propósito de este estudio es considerar varias tecnologías que apuntan a mejorar los mecanismos organizativos y económicos del desarrollo de la industria del transporte en la República de Kazajstán. Los autores examinaron la posible accesibilidad al transporte de las rutas más demandadas, con miras a crear un modelo universal de optimización de la infraestructura de transporte. El modelo de transporte de Astana se elaboró utilizando métodos de modelización matemática. El valor práctico de esta investigación es que los responsables de la formulación de políticas pueden utilizar sus resultados para optimizar los flujos de transporte y evitar costos de transporte adicionales.
Palabras clave: infraestructura, modelo de transporte, mecanismos organizativos y económicos de las tecnologías de transporte, enfoque entrópico, Astana, República de Kazajstán.

1. Introduction

Nowadays investment in infrastructure is regarded as one of the cornerstones of economic development strategies in post-Soviet countries (Rogers, Bruen,& Maystre, 2013: Pototskaya, Katrovskiy,& Chasovskiy, 2016; Vinokurov,& Libman, 2014, pp. 341-358; Akhmadieva,& Minnikhanov, 2016, p. 193). Therefore, the main issue of the XIII Forum of Interregional Cooperation of Russian Federation and the Republic of Kazakhstan was the formation of a quality transport and logistics infrastructure (Issabayev et al., 2016; Sagindikov, 2015, pp. 102-111).

Presently, there is an urgent need to develop transit areas of continental land routes (Suzuki et al., 2015; Emerson,& Vinokurov, 2009). This will enable Kazakhstan to integrate its national transport complex into the world transport system and ensurethe accessibility, security, and speed of cargo transportation between the East and the West (Mukhtarova, Pilipenko,& Madenova, 2016).

It is worth pointing out that over the last decade, the capital of the Republic of Kazakhstanhas been experiencing a dynamic development of all sectors of its transport infrastructure (Kuanyshbaev et al., 2013, p. 71; Mozharova, 2012). Largescaleconstruction projects with extensive funding are shaping the future appearance of Astana (Tokzhumanov, 2014, p. 22). However, the new city requires efficient transport for millions of its residents.

Nowadays, all big cities are facing problems that are related to increasing transport costs for the population (Adam, Bevan,& Gollin, 2016; Haghshenas, Vaziri,& Gholamialam, 2015, pp. 104-115). Theunderlying reason of this is the unbalanced development of transport systems and their noncompliance with respective demands of the urban community and economy. Thus, the list of relevant problems of sustainable development of cities includes the improvement of transport planning technologies. A quality solution of such problems is impossible without modern methods, computer-aided planning, in particular (Yamagata, Seya,& Murakami, 2016, pp. 25-43).

This study defines a transport model as an instrumentfor assessing the consequences of this or that urban-planning decision and a means of supporting managerial decision-making on all levels. Hence, the transport model allows assessing each scenario comprehensively and choosing the optimal one. In addition, it implies the creation of a system of data exchange between authorities and urban services, which, in turn,will help to systematize them (Rodrigue, Comtois,& Slack, 2013).

It is worth noting that the new designated lines and reorganized transport infrastructure will have a targeted impact specifically in the locations, where they are required the most. Therefore, any additional lines and infrastructures will not be as efficient andwill increase counterproductive financial charges.

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2. Method and Results

2.1 Methodological Framework

It is worth noting that mathematical methods of traffic flow modeling were created even back in the nineteenth century by analogy with physics problems, when various physical methods (liquid flow, probabilistic approaches, theory of entropy, and laws of mass or charged particle attraction) were used to plan the development of the transport infrastructure and model traffic flows (Haberman, 1998). The standard methodology for economic appraisal assumes partial economic equilibrium and cannot determine the distribution of impacts from the transport sector to particular households (Stubbs, Tyson,& Dalvi, 2017).

The entropic approach is considered the optimal one in terms of methodology (Radoutskiy, Shulzhenko,& Kemenov, 2016, p. 14). The described system can be infinitely complex, but the second law of thermodynamics expressly indicates the direction, in which the system will develop, the direction to the state, to which the system will tend (Martyushev,& Seleznev, 2006, pp. 1-45).

Despite the uniqueness of the urban system, it features certain properties that are common among economic macro-systems. Firstly, a dual-level nature of processes. It manifests itself in the special organization of the system, the interaction of its constituent subsystems, and the management of the economic development of the city. However, unlike economic volume systems, wherein the micro-level plays an auxiliary role, micro-processes that occur in urban systems (population migration, subsystem interaction, etc.) define its main properties. In this regard, urban systems have deeper analogies with thermodynamic systems. However, in the development of the transport model theory, the significantly more important aspect are the peculiarities of urban systems, the description whereof will enable expanding the possibilities of the models of such complex systems (McPhearson et al., 2016).

2.2 Main elements of the transport system of Astana

It is worth noting that transportation demand is formed based on statistical data on the population size, motorization, distribution of jobs across the territory of the city, and current land utilization. The analysis can be broken down by transport districts (parts of the city that are distinguished based on their gravitation towards certain elements of the transport network) or individual buildings and structures (Le, Somerville,& Wood, 2013).

In this study, a transport system is defined as a road network with the following characteristics: speed limit, traffic lights, traffic signs, and a number of lanes (Medury et al., 2016). In addition, it is important to know the information about the routes and schedules of public transport, location of stops, buildings, and greenery.

Then, based on the analysis of “transportation demand” and “transportation supply”, it is possible to construct various dependencies:

- determine the disproportions between supply and demand and offer solutions to minimize them;
- make suggestions in regards to the improvement of the parking policy;
- predict how changes in the land utilization structure can affect transportation, income from ticket sales, and profitability of public transport lines;
- predict how transport demand will increase with the future increase in motorization;
- how the transport system should be changed to rise to the challenge;
- make suggestions in regards to the development of public transportation, so that it best corresponds to the current and future “transport demand”.

It is worth noting that gathering data for the model only once is insufficient to solve such largescale problems, because then the transport will become outdated and the solutions will become irrelevant. The transport model requires a constant operator – a transport office, a certain structure within the city, whose task will be to create a system for data collection and continuous monitoring, analytical work, and preparation of recommendations for the development of the transport system.

2.3 Creating a transport supply model

Transport supply includes the infrastructure of transport systems that are included in the transport model. The main transport systems in transport models are individual transportation and urban public transportation.

The main elements of the transport model (by the example of the VISUM 12.5 (2013) project) are as follows:

- nodes – intersections;
- links – segments of the road network;

- transport zones – sources and goals of correspondence improvement;
- connectors – they connect the centers of transport nodes to the individual and public transport network.

In public transport systems, the above elements are supplemented by public transport stops and lines.

These elements are the abovementioned micro-level. At that, certain elements, such as legs, nodes, and junctions can be associated with the resistance (CR) function (Yakimov, 2013).

> The CR function is indicated for each element of the network. It shows the dependency of the time required to pass network element t_{akt} on the load q and capacity q_{max}, i.e. the result of the CR function is the time that is required to pass network element t_{akt}. The CR function can be set for each type of node, segment, and junction. When calculating the passage time of the route, it is necessary to sum up the CR function results for each element of the route. In other words, the total travel time is calculated as follows:
>
> – $t_{\text{akt}} = t_{\text{akt\_junction\_start}} + \sum_i t^i_{akt\_node} + \sum_j t^j_{akt\_leg} + t_{\text{akt\_junction\_destination}}$, where
>
> – $t_{\text{akt\_junction\_source}}$ is the relevant travel time along the junction from startingzone,sec;
>
> – $t^i_{akt\_node}$ is delays in node i, sec;
>
> – $t^j_{akt\_leg}$ is the relevant travel time along leg j, sec;
>
> – $t_{\text{akt\_junction\_destination}}$ is the relevant travel time along the junction to the destinationzone, sec (Ortuzar & Willumsen, 2001).

Another important issue that should be taken into account them creating the transport supply is the level of detail. Practical experience in the development of urban transport models allows concluding that correct modeling of individual transportation requires a level of detail of the representation of the road network down to individual exits from adjacent territories. With such a level of detail, the traffic flow will integrate into the network properly. When taking into account yard exits in the model, it is important to bear in mind that left turns are often prohibited when exiting or entering yard territories. Therefore, the authors call attention to the fact that such maneuvers should also be prohibited in the transport model. Without the specification of yard exits, the individual transport junctions will be placed directly onto intersections, which will produce an incorrect and improbable traffic flow redistribution in nodes. Furthermore, it will complicate the export of the micro-level to the simulation model.

2.4 Transport model: creation and operation issues

The creation of a basic model of Astana can take upwards of three months, depending on the promptness and accuracy of the provided data. This time can be used to train the experts of the customer who ordered the model. The elaboration and maintenance of the transport model of Astana requires about two-three experts with engineering education, specializing in transport and urban planning. Consequently, work with the model requires two-three workplaces with personal computers with relevant specifications.

2.5 Raw data

The first group of raw data includes the data that are acquired from executive agencies and urban services:

- socioeconomic statistics (schools, kindergartens, higher educational institutions – number of students; factories and business centers – number of jobs, etc.);
- certificates of sets of traffic lights;
- building and structure database;
- information about traffic accidents.

The second group of raw data includes data that are acquired through field examinations:

- characteristics of sets of traffic lights: cycles, passing phases, etc.;
- data about the number of lanes, markings, and traffic signs.

The third group of raw data includes data from automatic sensors.

The fourth group of raw data includes data from private organizations.

Acquired data should be converted into the .shape format (tables+geometry) for ordering and systematization. Intensity data are required during the calibration of the model.

Stages of development of a transport model of Astana

Stage 1: acquisition of raw (basic) data;

Stage 2: analysis and verification of raw (basic) data;

Stage 3: export of raw (basic) data into the computation module;

Stage 4: calibration of the computational model;

Stage 5: creation of a state transport model complex;

Stage 6: keeping the model up-to-date (update of raw data, checking of parameters that the model outputs: once every six months (year) – relief of intensity in certain points of the urban road network and comparison of data to the estimations of the model; recalculation of the model in areas with big objects due to be commissioned).

It is worth noting that the specificity of the multimodal transport system implies the optimal and most efficient use of space. This, in turn, helps cut costs and make the transport more comfortable to use (Hernández,& Peralta-Quiros, 2016). Consider several examples.

The basic elements of the transport model are presented in Figure 1. It should be pointed out that the proposed model allows room for bike lanes and pedestrian refuges.

Figure 1. Efficient use of transport system elements

Figure 2 shows the advantages by comparingcaroriented and multimodal streets.

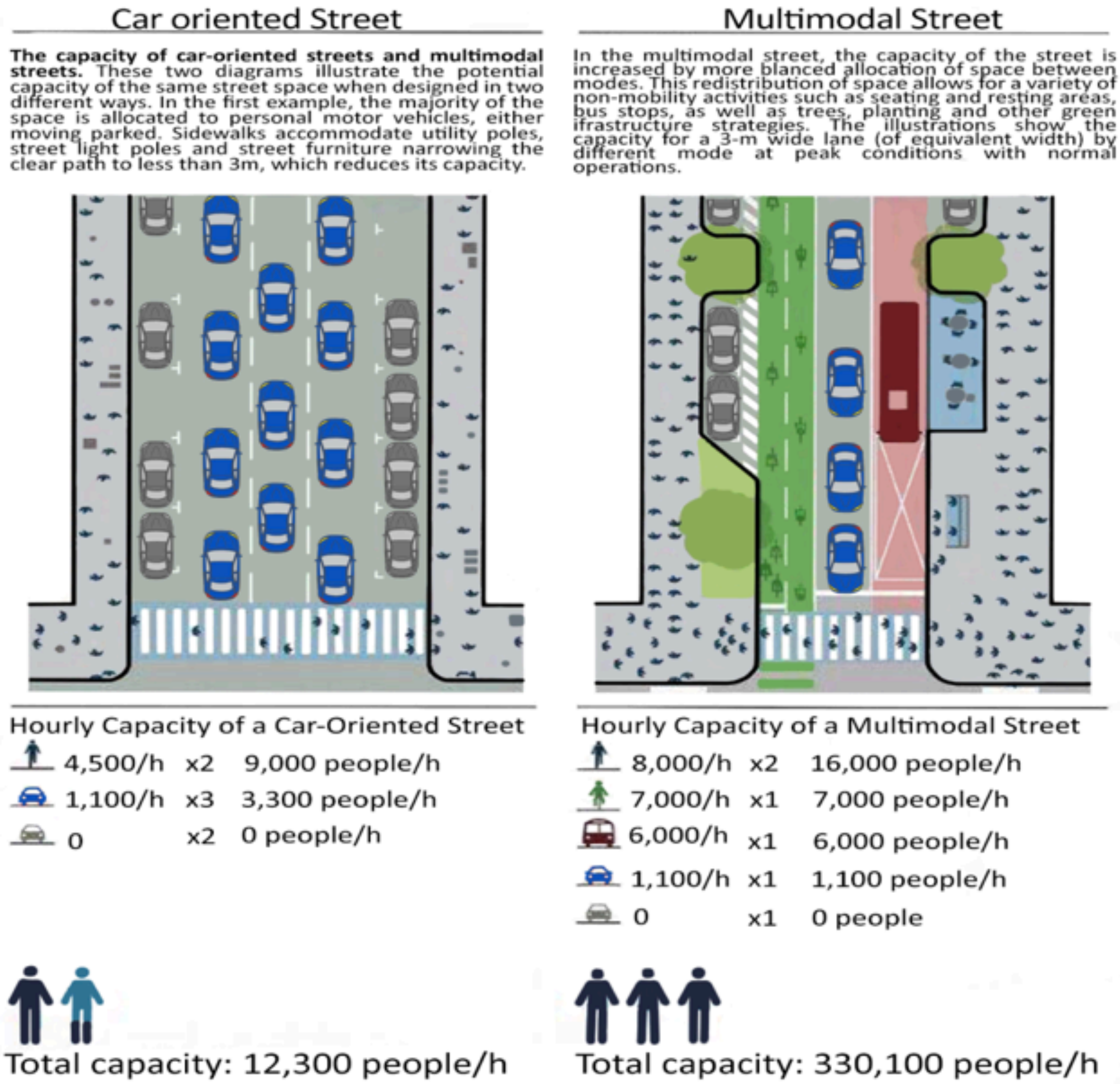

Figure 2. Comparison of the capacity of car oriented and multimodal streets

In addition, the proposed model is capable of assessing the use of public transport lines that are already in operation. Assume that the analysis of the passenger flow in a suburban residential district discovers that the public transport lines fail to properly connect the residential district with workplaces: institutions, companies, etc. This enables developing recommendations in regards to the creation of new lines, ones that would allow people to travel from their homes to work without stops and with minimum time required. The assessment of the potential transport availability of the most in-demand lines will be the foundation for the creation of a list of measures for optimizing and reorganizing the transport infrastructure.

It is worth noting that methods of real-time traffic flow monitoring and result verification are currently being developed (Calabrese et al., 2011, pp. 141-151).Developed countries also use the practice of investment in secondary roads. This method can be used in order to deliverbetter returns in peripheral areas by reinforcing intra-regional connectivity and fostering the productivity of localfirms (Gentile, & Noekel, 2016, pp. 978-983).

3. Conclusion

To sum up, the typical featureof the current development of the Republic of Kazakhstan is the rapid growth of cities. The transport model is regarded as a necessary condition for the creation of an efficient transport infrastructure.

This study described in detail the process of creation of a transport system, the implementation whereof will be efficient not only in Astana, but also in other big developing cities. The main stages of its development and operation were described.

The terrain, on which the capital of the Republic of Kazakhstan stands on the one hand and the need to concentrate the population, for work purposes, on small land plots that are unevenly distributed across the city on the other hand considerably complicates both the design of the urban transport system and the placement of new enterprises. If these problems are not solved properly, the transport system can get overloaded in segments where one least expects it, because each new segment of the network or new enterprise is accompanied by changes in passenger flows across the entire city.

The study shows, that the creation of a transport model does not require considerable investments and lengthy implementation. The use of separate transport and economic models in urban planning provides a limited view of economic impacts. At the same time, there currently is no largescale forecasting tool that would enable predicting the demand and utilized capacities of the transport infrastructure on the macro- and micro-levels.

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