MODEL RESEARCH OF EFFICIENCY
OF TRANSPORT SYSTEMS OF CITIES

Prof. YU.V.TROFIMENKO
State Technical University – MADI
D.Sc. M.S.YAKIMOV
Perm State Technical University, Russia

Summary: The article proposes an approach to assessing the modern transportation system of a large city based on linking the quality of the functioning of the existing transportation system of a city with the population's quality of life.

Author supposes, as we have a three-level system of transport models (pre-forecast, forecast, simulation), we can form an integrated system of decision-making process, aimed at ensuring effective functioning and development of the transportation system of a large city from the point of view of the quality of life.

Key words: A city, a transport, Hierarchy of needs by A. Maslow, optimal models, dual model.

In our "information" age where, mobility is often the key to success in an urban environment can not do without an effective means of meeting the transport demand. The difficulty of choosing "working" methods is the lack of standard quality, as well as the lack of tools to assess the demand for transport services. But in solving the problem of choosing instruments. The new horizons will be opening for quantitative assessment of community needs in the transport and the degree of satisfaction of these needs with the existing restrictions. The approach to the evaluation of the transport system of a large city, based on the representation of the transport system as part of an information system is proposed in this paper. This approach allows us to link the quality of the functioning of the existing transportation system of the city with the quality of life of the population.

1. The notion of efficiency of the transport system of a large city

For the correct formulation of the problem is required to determine the meaning of the concept - "an efficient transport system." EFFICIENCY – is a productivity of the process, operations or project, defined as the ratio of the effect (result) to the costs caused its receipt.

The efficiency of the transport system - is the ratio of useful outcomes of its operation to the resources invested. In other words, the efficiency - the ability to produce a particular effect (a measure of the effect produced.) The purpose of the functioning of the transport system of the city, as any natural-technical system is to improve the quality of life in the area where it operates (Lukanin V.N., Buslaev A.P., Trofimenko Yu.W., Yashina M.V.,1998).

Quality of life – is an indicator of the general well-being. System for measuring the quality of life is not enough formalized, and more often, the quality of life is seen as a system of

indicators of the extent to which the life strategies of people meet their vital needs [Lukanin V.N., Buslaev A.P., Trofimenko Yu.W., Yashina M.V. Modelling and optimal control of transport flows in megapolis. International Journal of Vehicle design, № 3, 1998].

The indicator used to assess the functioning of a city's transportation system is travel time (Lohse D., 1997; Ortuzar J.D., Willumsen L.G., 2001). Resource consumption –it is the energy and the area of the city. They are limited in objectives achieving. Energy, in turn, due to the imperfections of technology transforming it into useful transport work, as well as human factors gives rise to additional constraints on emissions, noise, risks of accidents.

That's why the main goal of effective transport system of a city is a take a minimum for the target function (minimization of transport correspondence implementation time of all residents by all modes of transport) in meeting the specified territorial restrictions.

As the target of the operation of the transport system of a large city it is advisable to consider the average or total transport correspondence implementation time. The average transport correspondence implementation time expresses the average time a person to commit a transport communications (Fig.1).

2. The optimal models. Setting the task

The task of forming an efficient transport system of a large city is a problem of optimization. It is the task of finding an effective use of resources in order to get the maximum effect. For the production of the optimization problem must be formulated as follows:

• specify (describe) variables;

• determine the degree of freedom;

• formulate the target;

• formulate restrictions.

Variables in our optimization problem will be the volume of movement of people across the city carried out by various methods:

• on foot

• public transport;

• the individual transport (car).

Each of these methods will bear their own, contribute to the target function of the problem. And this contribution will be different. In our case, dependent on the transport correspondence implementation speed in some way (5 km / h, 18 km / h, 30 km / h). Accordingly, each way movement will also have to waste different resources and to waste different energy.

2.1. The variables

For the production model of the optimization problem, we introduce the following

variables:

X_{rs1} - The number of people moving by walk in area «r» by type «s»; X_{rs2} - the number of people traveling by public transport in the area «r» by type «s»; X_{rs3} - the number of people moving by individual transport in area «r» by type «s»;

S - The number of types of the route the area ($S = 1,2,3$).

In forming an optimal model is important to consider how each correspondence goes through study area: transit, entry / exit, correspondence within the area.

The first type Transit - the route crosses the boundaries of the study area at two points;

Second type entry / exit - the route crosses the boundaries of the study area at one point;

Third type internal moving - the route does not cross the border the study area, and the centers are located within the area.

The number of areas «r» specifies the number of degrees of freedom and the dimension of the problem.

2.2. Degrees of freedom

Formulation of the optimal model implies some sampling of research - the division of the city in the area of transportation.

Divide the city in 10 traffic zones. Transportation zone are four types of areas. A breakdown of the territory proposed to take the following principle:

1. Town Center (Zone -1) (1 area).

For areas of this type is characterized by the maximum business activity.

2. Central areas close to the city center (Zone-2) (4 areas).

This type of areas is characterized by the dominant high-rise buildings and multi-functional use of the territory.

3. Remote areas (Zone-3) (3 zones).

This type of areas has own centers of business and social activity. Perspective – transformation of this areas into self-sufficient villages and autonomization.

4. Vast areas of low population density (low-rise buildings) (Area D-4) (2 areas).

2.3. The target function

The construction of the target function requires the specification of operational parameters of transport systems, and the calculation of the volume of transport correspondence for each zone.

Let us designate:

v_k - average speed of the vehicle of type k.

Let it be known that:

v_1 - average speed of travel by walk (km / h);

v_2 - average speed of travel by public transport (km / h);

v_3 - average speed of travel by individual transport (km / h);

l_{rs} - weighted with the number of people average part of length of correspondence passing through a zone r by type s, km:

$$l_{rs} = \frac{\sum_{i,j} l_{ijrs} k_{ijrs}}{\sum_{i,j} k_{ijrs}}$$

Where:

l_{ijrs} - a part of length of correspondence from area i to area j, passing through a zone r by type s, km;

k_{ijrs} - the number of correspondences from area i to area j, passing through a zone r by type s per day, people.

Then, the target function will be:

$$Z = \sum_{r=1}^{E} \sum_{s=1}^{3} (\frac{1}{v_1} \cdot l_{rs} \cdot X_{rs1} + \frac{1}{v_2} \cdot l_{rs} \cdot X_{rs2} + \frac{1}{v_3} \cdot l_{rs} \cdot X_{rs3}) \rightarrow \min$$

Where:

E - number of transport zones.

In this formulation of the problem the target parameter of transport system working is minimization of the total transport correspondence implementation time.

2.4. Restrictions

As a set of constraints on the target function, we use six types of constraints:

• Restrictions on the demand for movement in the study area;

• Restrictions on the length of the existing road network;

• Restrictions on emissions of pollutants;

• Restrictions on the risk of road accidents;

• Restrictions on the existing rolling stock;

• Restrictions on noise pollution.

3. Solution of the optimal model for the city of Perm

3.1. Solution of the direct model

The result of the model solution is a set of values of 90 variables X_{rsi}, each of which specifies the number of people traveling in the relevant area, the appropriate type and transport mode. The total amount of time required to meet current best in the transportation needs of all people (the target function) is - 995 406 hours in the diurnal cycle of transport needs, which is 35% less than the current amount of time - 1,546,779 hours. This is achieved by changing the existing allocation in traffic demand on different methods of movement, while maintaining the existing level of transport supply and basic parameters of the environment - the level of harm from road accidents, air pollution and increased traffic noise in terms of one citizen. Distribution on cartogram of the parameters found distribution of transport demand by zone is shown in figure 2.

The originality of the approach is that you can change the location, size and number of research areas (depending on the task) and each time, building and solving the optimal model, get the optimal allocation of demand in selected areas. Variability of the parameters at the same time forming a new distribution of traffic demand are: length of the carriageway in researched areas, limiting environmental pressures, the demand for travel.

3.2. Solution to the dual model

The model presented above is linear. All the unknowns are the target function and constraints are linear too. Using the principles of the theory of linear programming to this model, we can construct a dual model (Taha H.A., 1997).

The solution has a practical value. The solution of the dual problem determines the value of each of the resources consumed by the transport system in terms of its target function.

For example the solution of the dual problem for Perm indicates that the most effective measures from the point of view of reducing the total trip time should be aimed at developing street and road network in zone 4. Each new kilometer built in the zone will reduce the total daily trip time in the city by 110 hours; while the marginal length of new roads in this zone must not exceed 50 km (the cost of 4-lane road is 100 million rubles, the cost of a work hour is 200 rubles, which saves 44,000 rubles per day, with payback period of 568 days). Consequently, if we know such estimates for each of the resources consumed, as well as the financial resources available to a community, we will be able to formulate an economically sound program of measures to improve the efficiency of the functioning of a city's transportation system.

4. Correlation of different types of transport models

The aspect we consider particularly important is finding the place for the presented optimal models in the system of various types of existing models within the field of study of

transportation systems. From this standpoint the proposed models can be classified as pre-forecast, whose main goal is formulating the scenarios of the development of transportation systems, as well as preparing these scenarios for subsequent forecasting. The assume relation of the models of variable function is show on the picture 1 on the example of known classes of models.

As we have a three-level system of transport models (pre-forecast, forecast, simulation), we can form an integrated system of decision-making process, aimed at ensuring effective functioning and development of the transportation system of a large city from the point of view of the quality of life.
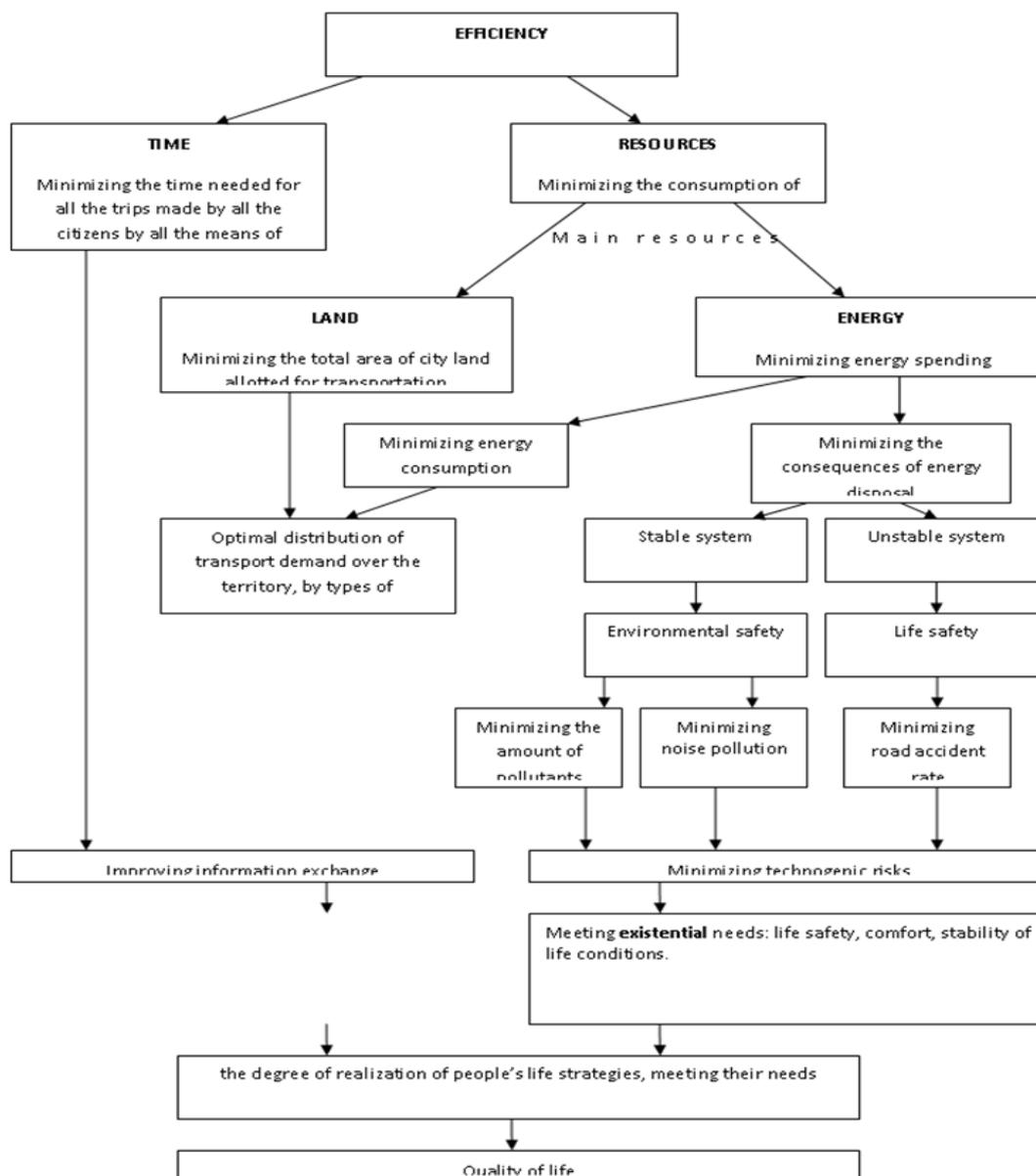

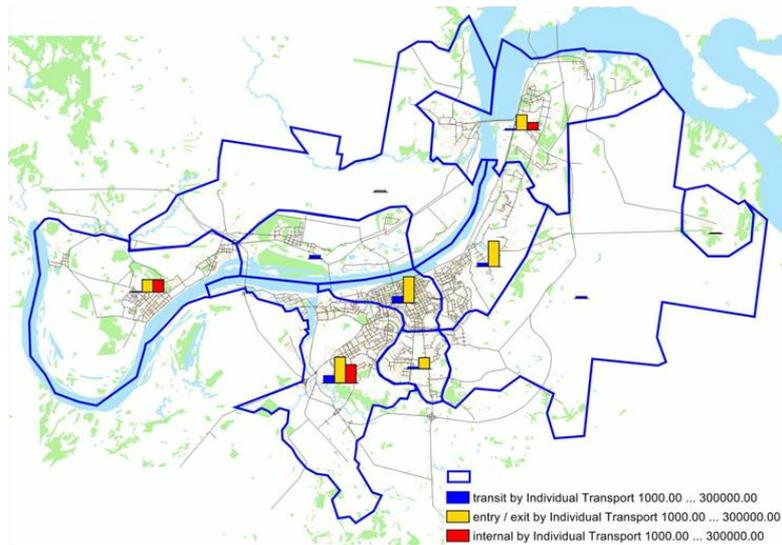**Fig 1.** *Assessing the efficiency of a city's transportation systems*

Fig 2. *Distribution of the transportation demand for individual transport. The map shows a volume of different types of moving of people on the territory of the city (man/day)*
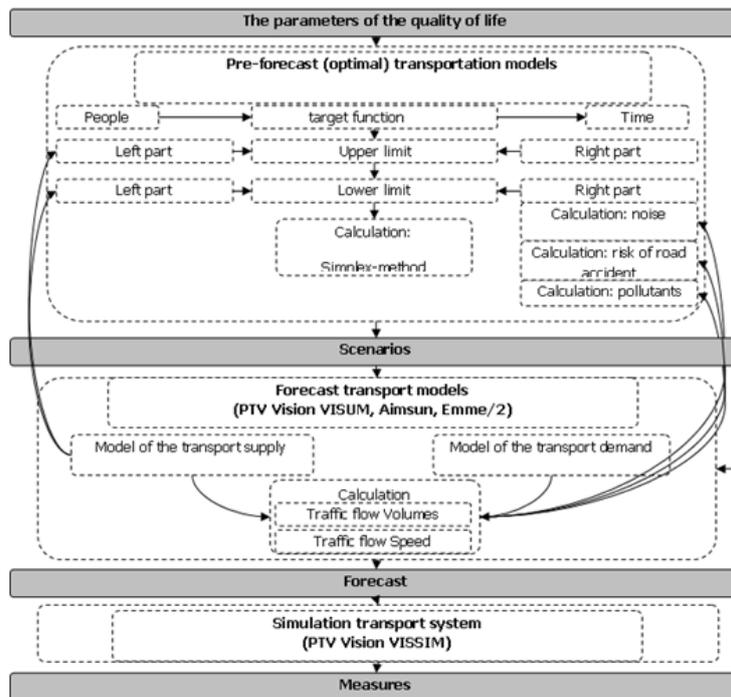

Fig 3. *Relation of a three-level classification of the transportation system of cities*

References

[1]. Lohse D. Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung, Band 2: Verkehrsplanung, 2. Aufgabe, Berlin, Verlag für Bauwesen GMbH. - 1997. – P. 326.

[2]. Lukanin V.N., Buslaev A.P., Trofimenko Yu.W., Yashina M.V. Modelling and optimal control of transport flows in megapolis. International Journal of Vehicle design, № 3, 1998

[3]. Maslow A. Motivation and personality. Rev. ed. 1970. New York: Harper and Row.

[4]. Ortuzar J.D., Willumsen L.G.. Modeling Transport. John Wiley & Sons Ltd.- 2001. – P.594.

[5]. Taha H.A.. Operations research: an introduction. Prentice Hall International, 1997 ♦