Organization of Yerevan City Traffic Flow Modeling Process

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Abstract. The article presents the modeling types and touches upon the application of the gravity model on the street and road network (SRN) of Yerevan. Preliminary data necessary for modeling are provided. The study of the movement structure of traffic flows has been performed by the correspondence matrix method. For the calculation of SRN load, as a criterion for estimating route and inter-district “transportation” distances, the concept “generalized price” has been applied. The calculation of the correspondence matrices with the gravity model is presented.

Introduction

The problem of modeling traffic flows for the city of Yerevan is topical due to the increase in the traffic volume on its SRN.

A number of approximations of the actual properties of the system are used in the modeling. The best model should be accurate and simple at the same time. In order to fully examine the characteristics of the traffic system on the SRN of Yerevan, simple models can be used, in which significant approximations can be made and a number of details can be omitted.

Models are divided into two types: mathematical and non-mathematical. Mathematical models are represented by equations. Non-mathematical ones include identical models, which use a real system set with identical electrotechnical characteristics - special modeling equipment and digital imitation models, in which the system is modeled with software. Such non-mathematical models, when constructed correctly, give a more accurate view of the object with smaller approximations than mathematical models, but require higher costs to be created, at the same time providing lower level of accuracy of system research and prediction behavior in case of serious changes of the initial concept [1].

It can be concluded that in order to get the full characteristics of the whole system, it is desirable to apply the mathematical model of approximation first, and then apply the non-mathematical model for detailed specification of the characteristics of system elements.

Materials and Methods

In modern conditions, the mathematical model must take into account the following important points in the process of the generation of traffic flows [2].

- Network capacity plays an important role in the selection of traffic flow routes under the conditions of high SRN load.
- The intensity of traffic is disproportionate: it changes drastically during the day, as well as depending on the days of the week and the time of the year.
- Various factors affect the choice of routes and movement modes, such as time, purpose of the movement, etc.
- In the public transport system, there is a common interdependence between the generation of automobile and passenger flows.

At present, many models have been developed that make it possible to take into account this or that characteristic of the traffic flow generation process. This article presents a complex model of the transport system of a city as big as Yerevan, which allows modeling the movements of all types of transport vehicles taking into account the aforementioned concepts.

Preliminary data for modeling are population mobility, i.e. the average quantity of movements by residents for different purposes during the day, as well as data on the placement of objects in the city plan, which are considered to be gravity points [3, 4].

In order to predict the structure of the movement, it is necessary to make a calculation using the correspondence matrix [5] between the calculation districts of the city or the highways, indicating respectively the different types of movement (pedestrian, automobile, public transportation, freight, etc.), according to the goals and the hours of the day.

For the purpose of examining transport correspondence, the entire SRN of the city is divided into conventional transport districts [2, 6]. The number of conventional transport districts is calculated according to the following formula:

$$M = Q \cdot X_1/(20\, X_2)\ , \qquad (1)$$

where Q is the number of urban population, thous. people, X_1 and X_2 are coefficients that characterize the density ($Y_{p.}$) and the density of the highway SRN (Y_m). The values of X_1 and X_2 coefficients are given in the tables (Table 1, Table 2) depending on the population and highway streets density.

Table 1. The Value of X_1 Depending on the Population Density

$Y_{p.}$, thous. person/km^2	< 2	2 - 4	4 - 6	6 - 8	> 8
X_1	1,0	0,95	0,90	0,80	0,70

Table 2. The Value of X_2 Depending on the Population Density

$Y_{p.}$, thous. km/km^2	< 0,4	0,4 - 1,4	1,4 - 2,3	2,3 - 4,2	> 4,2
X_2	1,0	1,2	2,0	4,0	12

The idea of a balanced flow distribution is implemented to model SRN load. The load of the public transport system can be calculated with the "optimal strategy" model implemented in the route system of different countries [3, 7].

In the case of load calculations, as a criterion for assessing routes, and inter-district travel distances in the case of the correspondence calculation, the "generalized price" of the movement is applied, which includes various factors, such as the time or the price (monetary costs) of the movement. The "generalized price" of the route denotes the criteria on the basis of which the user assesses the alternative routes and modes of transportation. The generalized price is determined as the weight sum of the constituent parts, which express the impact of various factors on the assessment of the route. Generally, it can include the following components:

- Travel time,
- Additional delays on different elements of the transport network (parking time, waiting time at intersections, etc.),
- Conditional increase of additional time preconditioned by modeling of different characteristics of the transport network and transport management means.

The main component of the generalized price is the travel time, so the other components are expressed in conventional minutes and added to the time.

The route with the lowest generalized cost between the two districts (highways) or network junctions is considered the optimal route.

The generalized price is used in the calculation of matrices of inter-district or highway street correspondences as a comparative for the assessment of alternative routes.

The complex prediction of the transportation network load requires the calculation of a large set of correspondence matrices that includes the movement purposes of different transportation means for different times of the day. Daily disproportions of traffic volumes are taken into account, calculations are made for the detection of congestion situations on the SRN, determination of traffic flow delays and development of a route optimization model.

If traffic demand exceeds network capacity, congestion is inevitable, no matter how advanced the traffic management system is. Congestions at highways are formed at "narrow" or "critical" intersections, where the demand for vehicles exceeding the capacity is paramount, and then such congestion spreads to "narrow" places at other intersections.

Correspondence matrices are calculated using the gravity model [4, 8], taking into account movements for different purposes.

According to the gravity model, the correspondence is equal to:

$$F_{ij}^{ab}=A_i O_I^{ab} B_j D_j^{ab}\ exp\ \left(-\lambda^{ab} C_{ij}^{ab}\right), i,j \in M\ , \tag{2}$$

where A_i and B_j are the equilibrium coefficients and are determined by the following condition:

$$\sum_j F_{ij}^{ab} = O_i^{ab}, \qquad \sum_i F_{ij}^{ab} = D_j^{ab}\ . \tag{3}$$

M is assigned as the number of districts under calculation, F_{ij}^{ab} are the correspondences from district *i* to district *j*, from *a* target group object to *b* target group object. The value C_{ij}^{ab} is the "transportation distance" between *i* and *j* districts. The cost of the optimal route between districts can be used as a characteristic of transportation distance. The dependence of the transportation distance on target groups *a* and *b* is conditioned by the fact that the cost of the route for the whole day or the average cost of "going" or "coming" can be implemented for different types of movement [3, 9]. For example, in case of Yerevan, the following distance characteristics can be implemented with verification:

$$C_{ij}^{day}=\sum_t \frac{1}{2}\left(C_{ij}(t) + C_{ji}(t)\right),\ \text{daily average}\ , \tag{4}$$

$$C_{ij}^{t}=C_{ij}(t),\ \text{(momentary)}\ , \tag{5}$$

$$C_{ij}^{peak} = \frac{1}{2}\left(C_{ij}\left(t_{morning}\right) + C_{ji}\left(t_{evening}\right)\right), \text{morning and evening rush hours}\ , \tag{6}$$

where $C_{ij}(t)$ is the optimal cost of transport network load, formed during *t* time period, averaged by modes of movement (light vehicles, public transport, etc.), *t* acquires intermittent values: morning, daytime, evening.

The λ^{ab} coefficients determine the "sensitivity" of the correspondence to the distance factor. The values of these coefficients are determined by experimental research. For example, for rush hours ("peak" period), its typical value is 0.065. Taking into account the coefficients of daily disproportion-..K_t^{ab}, *t* = 1, ..., T, the correspondence matrix for the *t* period should be presented as follows:

$$F_{ij}^{ab}(t) = K_t^{ab}, F_{ij}^{ab}. \tag{7}$$

For movements having different purposes, those coefficients are determined by analyzing the disproportionate loads of different elements of the transport network, as well as experimental data on arrival and departure disproportions from different parts of the city. To this end, transport correspondences for each intersection of each highway street are examined. The hourly intensities for the period under study are averaged and as a result, the N_{avg} intensity is determined for each direction of the intersection [10].

The rush hour load coefficients are:

$$K_{morning}^{peak} = N_{morning}^{peak}/N_{avg.,}\ \text{(in the morning)}\ , \tag{8}$$

$$K^{peak}_{evening} = N^{peak}_{evening}/N_{avg.,} \quad \text{(in the evening)}\,, \tag{9}$$

where $K^{peak}_{morning}$ and $N^{peak}_{evening}$ are the intensities of traffic during the rush hours in the morning and in the evening respectively, unit/hour.

The total average load coefficients for the morning and evening rush hours at the intersections under study will be calculated with the [2, 10] following formulas:

$$K^{total}_{morning} = 1/n \sum_1^n n\, K^{peak}_{morning} \quad \text{and} \quad K^{total}_{evening} = 1/n \sum_1^n K^{peak}_{evening}\,, \tag{10}$$

where n is the number of linked intersections. The coefficients of rush hour loads of traffic intensity are applied for the formation of correspondence matrices of the traffic flow on the SRN [4, 8, 11]. For each *ij* route the load coefficients for morning and evening rush hour are determined with the following formulas:

$$K^{peak}_{morning\ ij} = (\textstyle\sum_1^n K^{peak}_{morning} + K^{total}_{morning})/(n+1)\,, \tag{11}$$

$$K^{peak}_{evening\ ij} = (\textstyle\sum_1^n K^{peak}_{evening} + K^{total}_{evening})/(n+1)\,. \tag{12}$$

The main components of the software for modeling are [11]:

- Graphic editor of the transportation network,
- Modeling means:
  - *Matrix calculation block,*
  - *Network flow distribution algorithms,*
  - *The use of functions,*
  - *Operational language and calculations in package mode,*
- Graphic representation means and data extraction.

Matrix calculation block allows to calculate the inter-district price and distance matrix, as well as to calculate matrices by elements according to the formulas specified by the user. Besides, matrix balancing algorithms are provided for arrival and departure from each district based on a selected database. Having the inter-district price matrix - $\{C_{ij}\}$, correspondence matrix - $\{\exp(\lambda_{ij})\}$ can be calculated with further equilibriums.

Automobile network flow distribution is implemented using the equal distribution algorithm of several (arbitrary amount) users of the transportation network. Network and route distribution algorithms may be provided for public transport [12].

All the calculation formulas are input into the software in the form of expressed logos. Calculations can be made both in the interactive mode using the dialogue list and in package mode using the software operational language. In the latter case, the calculation operations for the distribution of all the necessary matrices and flows are recorded in the text page (file) in the form of a management command, after which the management page can be issued multiple times for implementation [11, 13].

Conclusion

The paper presents a mathematical model that can be introduced to solve the problems of the transport system of the city of Yerevan. The typical characteristics of the model are:

- Calculating the differences in distance and time disproportion characteristics of movements for different purposes,
- Load of transport network elements and calculation for the difference in movement structure for different times of the day,
- Sequential application of the total price of transportation as criteria for assessing inter-district transportation distances and routes,

- Accurate calculation of the correlation of generalized price of the routes, correspondence values, and the results of network element loads.

By testing the model, it is possible to achieve acceptable consistency of the calculated and obtained actual data. The model operates and can be used for the transportation network or to predict situations in case of structural changes in urban planning. The prediction can be made for any time of the working day.

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