World Applied Sciences Journal 23 (Problems of Architecture and Construction): 165-171, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.23.pac.90033

Method for Investigating Variants for Modernization of the Road Network Section in the Gis Environment

Jurij Kotikov and Valerij Lukinskij

Department of Transportation Systems, Automobile and Transportation Faculty,
St. Petersburg State University of Architecture and Civil Engineering,
Vtoraja Krasnoarmejskaja ul. 4, St. Petersburg, 190005, Russia

Abstract: The present article discusses the methods to substantiate modernization of a road transport interchange on the basis of traffic modeling and calculating its parameters in the GIS environment. For support of the method in the GIS environment in ArcGIS, a pyramid of road network models is created, which include the central-axial, corridor and lane models. This article presents the algorithm for a calculation of modernization variants with the use of statistical investigation of the traffic on an existing section of the road network. Using geographically-referenced cost matrices of correspondences makes it possible to predict particular and summed traffic volumes, fuel consumption and other parameters used as criteria for optimization. The entire chain of actions is demonstrated on the example of pre-project investigation of the possibility to modernize Krasnogvardeyskaya square in Saint-Petersburg. The article presents an economical evaluation of the discussed variants. Topological similarity of various circular elements of the road network – from the simplest discussed section to circular roads of the largest cities – provide the conditions to use the method for random elements of this type.

Key words: Road transport · Road interchange · Motor vehicle · GIS ArcGIS · Transport model · Method for modernization · Matrix of correspondences · Circular element of the road

INTRODUCTION

In order to solve transport tasks, the software ArcGIS manufactured by Esri is widely used [1]. Perfect continuity of its module Network Analyst [2] makes it possible to model multi-modal networks, whereas its 3D tools allow modeling 3D networks [3, 4]. There are a lot of examples for integrated solutions for transport tasks in the example ArcGIS – for example, the projects Traffic Analyst [5], TRANS-TOOLS [6], WorldNet [7].

But, despite the fact that ArcGIS is widely used, there still is a possibility to implement innovations, for example, when modeling the traffic on circular elements of the road network (RN). Terminology from the work [8] is used.

MATERIALS AND METHODS

Components of the examined method are:

- Forming a GIS model and geographic database (GDB) of RN;
- Preparing maps and networks of the investigated fragments of RN;
- A statistical investigation of traffic on the existing fragment in order to model the historical traffic – with recording the traffic intensity on all entrances and exits of the fragment;
- Modeling traffic in the GIS model with compiling maps of traffic intensity on condition of providing their equality on entrances and exits in all the discussed variants;
- Calculating the volumes of traffic and other parameters on matrices of correspondences;
- Technical-economical evaluation of variants;
- Discussing the methodical compilations.

Corresponding Author: Jurij Kotikov, Department of Transportation Systems, Automobile and Transportation Faculty, St. Petersburg State University of Architecture and Civil Engineering, Vtoraja Krasnoarmejskaja ul. 4, St. Petersburg, 190005, Russia. Tel. +7(921)3390541.

Fig. 1: Three-level circumstantiation of RN: a - model network on the roads' central lines; b - model network on the basis of traffic corridors; c - model network on the basis of traffic lanes; zigzag arrows - zones of the possible lane change

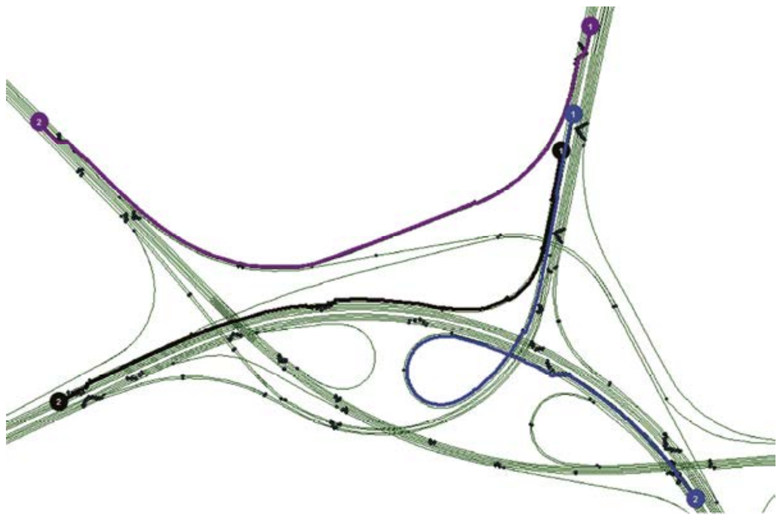

Fig. 2: Example of a route with implementation of changing between traffic lanes

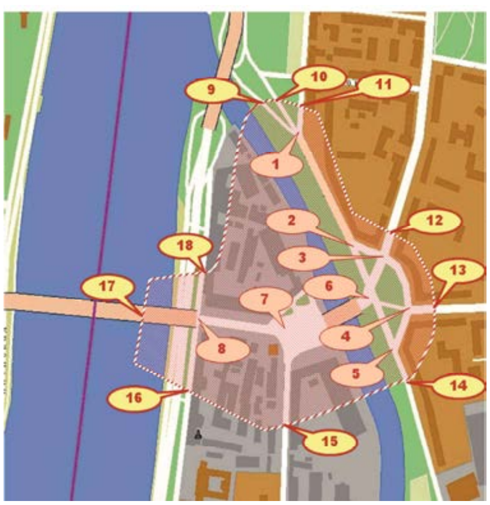

Fig. 3: The investigated area

The Main Part

Forming a GIS Model and Geographic Database (GDB) of RN:

1.1. For the RN layer, a hierarchical pyramid of models with various degrees of detail [3, 9, 10] is compiled. Schemes of a single interchange are shown in Fig. 1.

1.2. In order to carry out a non-planar network analysis in the example of ArcGIS, a system of models "central axis of the road – corridor of movement – lane of movement" is created – the so-called hierarchical lane-oriented 3D-model (ILO-3D-M), as in work [10]. The example of the lane model ILO-3D-M is presented in Fig. 2.

1.3. As the GDB was being created, the information from the works [3, 11, 12] was used. A GDB for Fig. 2 contains 7 sets of classes of spatial objects with 22 classes of objects; 12 classes of relationships; 3 sets of network data. The total number of attributes is 258.

Preparation of Maps and Networks of the Investigated Fragments of RN: Algorithm for solving the tasks of modernization of the interchange is demonstrated in the example of evaluation of the possibility to replace the radial 2-nodal interchange in the area of Krasnogvardeyskaya square in Saint Petersburg with a circular interchange [13].

2.1. A borderline of the areal of the existing interchange is formed, with recording its entrances and exits (Fig. 3).

Fig. 4: Maps with the analyzed networks: *a* - the existing variant; *b* - the perspective variant

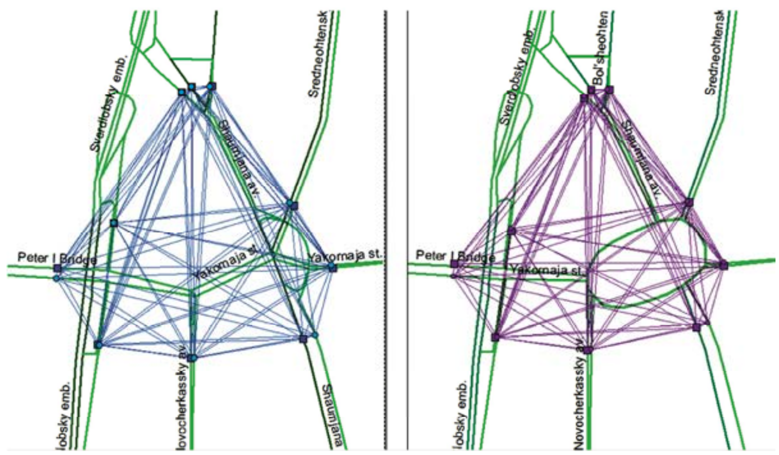

Fig. 5: The geodetically-referenced matrix of correspondences for the existing (left) and the projected (right) schemes of traffic organization

2.2. In the Network Analyst, a Network N0 is formed for the existing fragment (Fig. 4a). At the same time, the Network N1 is formed for the modernization variant 1 (Fig. 4b) (if there are several variants, then, respectively, Networks N2, N3 etc.).

2.3. For the existing and perspective variants, geographically-referenced Euclid matrices of correspondences Mde_N0 (Fig. 5a) and MDe_N1 (Fig. 5b) [14, 15] are formed. The condition for the comparative analysis is their geometrical and topological coincidence.

Investigation and Calibrating the Historical Traffic:

3.1. The traffic is statistically analyzed on each entrance/exit of the fragment, as well as on a number of internal points (for balancing the model). Traffic intensity and composition are measured. 18 observation points were used – 10 points on entrances/exits and 8 internal points. For two observation sessions (3.25 hours long during the morning and evening rush hours) all observation points recorded 160 632 traffic units. Classification of the traffic is limited by two vehicle types: passenger cars and trucks, with the reduction factor 1:2.

3.2. Statistical data are entered into an Excel table, which will be used for calibrating the model, calculating the derivatives and modernization variants.

3.3. The model balancing is carried out – between the total figures of traffic units at entrances and exits, with checking the traffic intensity at internal points (compiling a balanced Excel table).

3.4. A submatrix for entrance/exit points is calculated.

Fig. 6: The route and the route description: left - the existing variant of the interchange; right - the perspective variant

		Exits																		
	№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Sum
Entrances	1		1469								59	775								2303
	2	249					1718													1967
	3		386				1283						1095							2764
	4			610			857							1052						2519
	5				1063										626					1689
	6			874	806	803		3156												5639
	7						1935		2689							1566				6190
	8							1661									154	3334	34	5183
	9	666																		666
	10																			0
	11	803																		803
	12			1349																1349
	13				915															915
	14					1021														1021
	15							1159												1159
	16								246											246
	17								1569											1569
	18								1048											1048
Sum		1718	1855	2833	2784	1824	5793	5976	5552	0	59	775	1095	1052	626	1566	154	3334	34	37030

Fig. 7: The matrix of correspondences for the existing scheme of traffic organization (morning hush hour), unit/hour of observation; columns and lines - exits; the rightmost column - sums.

Modeling Traffic in the GIS Model:

4.1. In the Network Analyst (with the use of methods in [13]) movement of a single vehicle for all the possible routes in the network is modeled (corresponding to the relationships of matrices MDe_N0 and MDe_N1) from entrances to exits (with path patterns indicating the distance D, time of movement T, fuel consumption F, other parameters X, Y etc.). Fig. 6 shows examples of routes with the same initial and terminal points of RN.

4.2. With the help of path patterns, table matrices of correspondences MD_N0 (the existing one) and MD_N1 (the perspective one) are created for entrance/exit points, with indication of route lengths between the points.

4.3. The corresponding table matrices are created – MT_N0 and MT_N1 – time of movement; MF_N0 and MF_N1 – fuel consumption; MX_N0 and MX_N1, MY_N0 and MY_N1… – other parameters.

4.4. Elements of networks N0 and N1 are filled with hourly intensities of traffic at entrances/exits of the balanced model (entrances/exits 9–18, Fig. 7–9). The values for the internal ridges of the network N0 are taken from the balanced Excel table (Fig. 7, 9a).

The networks N1 are calculated on the basis of proportional dividing of each entrance traffic flow between groups of vehicles spreading to all the other outer peaks, in the amount proportional to the total exits from these outer peaks. Traffic intensities on internal ridges are formed by adding partial flows for the ridge from each entrance (Fig. 8, 9b).

Calculating the Volumes of Traffic and Other Parameters:

5.1. Matrix MA_N0 is formed with the number of vehicles passed through the corresponding routes; similarly for the perspective variant – matrix MA_N1.

	Exits																			
	№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Sum
Entrances	1		1469								59	775								2303
	2	249						4230												4479
	3		3094										1095							4189
	4			2910										1052						3962
	5				3312										626					3938
	6					3010										1495				4505
	7						2001		2689											4690
	8							1661									154	3334	34	5183
	9	666																		666
	10																			0
	11	803																		803
	12			1278																1278
	13				915															915
	14					1021														1021
	15						1089													1089
	16								246											246
	17								1569											1569
	18								1048											1048
Sum		1718	4563	4188	4227	4031	3090	5891	5552	0	59	775	1095	1052	626	1495	154	3334	34	41884

Fig. 8: The matrix of correspondences for the perspective scheme of traffic organization (morning hush hour), unit/hour of observation; columns and lines - exits; the rightmost column - sums.

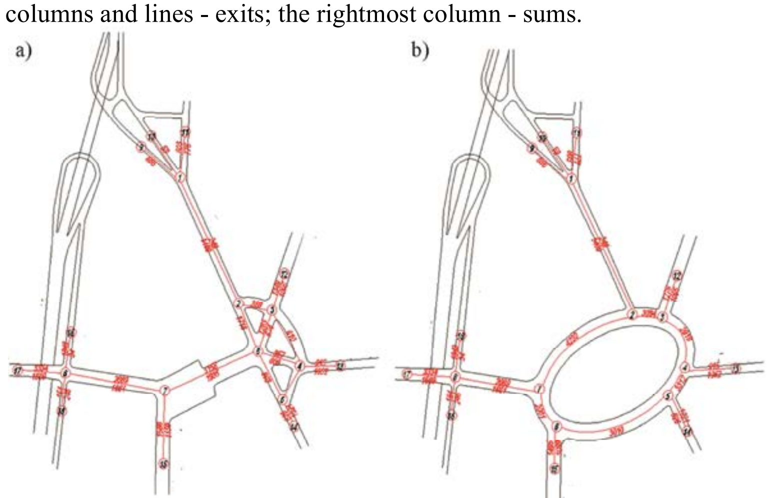

Fig. 9: Diagrammatic maps of traffic intensities, unit/hour: a - the existing variant of the interchange; b -- the proposed scheme of the circular interchange.

5.2. Through the element-wise multiplication of values of matrices MA_N0 and MD_N0 for the existing variant, matrix MDQ_N0 is formed for distance volumes of traffic along the routes, veh⋅km); similarly for the perspective variant – matrix MDQ_N1.

5.3. Through the element-wise multiplication of values of matrices MA_N0 and MT_N0 is formed the matrix MTQ_N0 temporal traffic volumes along the routes, veh⋅hr; similarly for the perspective variant – matrix MTQ_N1.

5.4. Through the element-wise multiplication of values of matrices MA_N0 and MF_N0 for the existing variant is formed the matrix MFQ_N0 of summed fuel consumption values along the routes, veh⋅l; similarly for the perspective variant – matrix MFQ_N1.

5.5. Similarly are formed matrices MXQ_N0, MXQ_N1 etc.

5.6. By summing the elements of the matrix MA_N0, the total number of vehicles that passed through the existing interchange is estimated (value A0); on the matrix MDQ_N0, the distance volume of traffic is counted for the interchange D0, similarly, the summed parameter are counted: the summed time T0; the total fuel consumption F0; and X0, Y0 etc.; similar operations are carried out for the perspective variant, with calculation of parameters A1, D1, T1, F1, X1, Y1 etc.

5.7. Values are calculated for a vehicle from the generalized traffic flow in the existing interchange: the average speed V0 = D0/T0; linear fuel consumption FD0 = F0/D0; hourly fuel consumption FT0 = F0/T0; derivative parameters from X0, Y0 etc. Similar operations are carried out for the perspective variant, with calculation of parameters V1, FD1, FT1, derivative parameters from X1, Y1 etc.

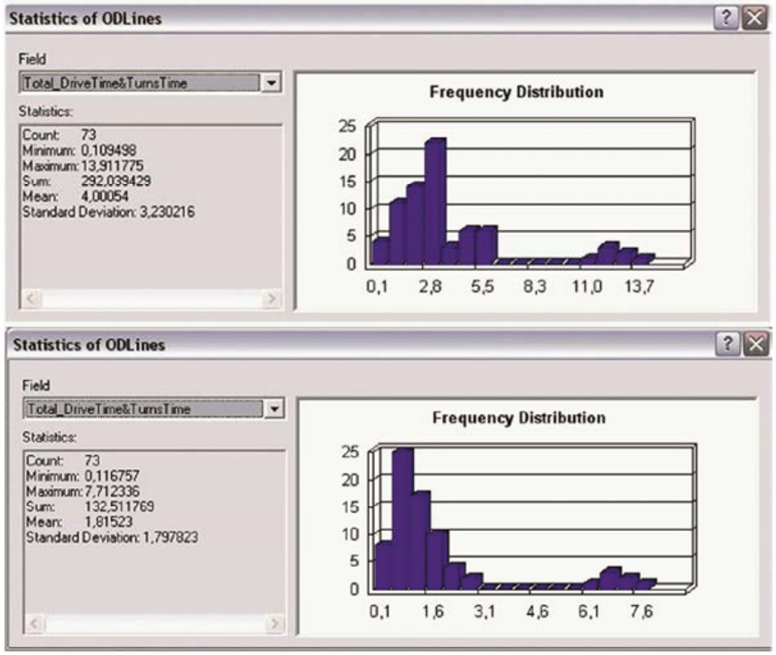

Fig. 10: Diagrams of the travel time for the existing (top) and projected (bottom) schemes of traffic organization

5.8. In the Network Analyst, statistical diagrams are displayed, as in Fig. 10.

5.9. Variant can differ. For example, for the geometrical solution fig. 4b, 9b, all the 3 models of the pyramid ILO-3D-M (fig. 1) have been tried, and for the lane model – also the 3-, 4- and 5-lane variants. For each scheme variant, a lot of expectation variants and temporal forfeits have been tried – using the methods of imitational modeling [16]. As a result, the total number of variants was several hundreds.

Evaluation of the Technical-economical Efficiency: A new scheme of traffic organization will decrease the travel time in the section of RN. For evaluating the economical effect, the correspondences matrices data were used. It was assumed that the average fuel consumption is 12 l / 100 km and the average speed is 30 km/h. The difference between the yearly costs of fuel for the existing and the perspective schemes was 5 298 000 (l/year), or 105 967 000 (rubles/year).

The difference between the yearly costs of fuel for the initial variant of the interchange and the four-lane circle was 106 million rubles, which, considering the modernization cost of 200 million rubles, makes the payoff period 1.9 years.

Discussing the Methodical Patterns: If there is topological unity between different circular elements of the road network, there also are particularities. For example, the circular road has an internal border. It, in combination with the external border, creates a buffer, and many entrances/exits are distributed on these both borders. The traffic organization inside and outside of the circle will probably differ.

Other particularities: circular structures with deformation and interruptions [17], presence and interaction between several sub-circles [18], adjacent circles [19], introduction of payable circular roads [20] – this is all important for Saint Petersburg. And the presented method can become the core for the corresponding more global and/or detailed models.

CONCLUSIONS

- The algorithm of operations is contemplated from the viewpoint of its automation with the help of ArcGIS.
- The topological unity of various circular elements of the road network creates conditions for using this method to random elements of this type. The matrix of correspondences of the circular form factor must include all the entrances/exits on both borders, as a random circular element of the road network has a belt polygonal areal with the internal and external circular borders, as the topographic base.
- As the discussed method can be applied to both the simple circular element of the road network, and to the circular road of a large city, it is important to ensure deep automation of the combination of the

operations and embedding them into more general methods for optimization of the urban structure layers.

REFERENCES

1. ArcGIS for Desktop. Date views 15.06.13 http://www.esri.com/software/arcgis/arcgis-for-desktop/.
2. ArcGIS Network Analyst. Date views 15.06.13 http://www.esri.com/software/arcgis/extensions/networkanalyst/.
3. Butler, A., 2008. Designing geodatabases for transportation. Redlands, US: Esri Press, pp: 494.
4. Simard, S., 2010. The development and deployment of a GIS tool for transit network design. A thesis presented for the degree of Master of Applied Science in Civil Engineering. Waterloo, Ontario, CA. Date views 15.06.13 http:// uwspace.uwaterloo.ca/ handle/ 10012/ 5182/.
5. Rapidis: Traffic-analyst. Date views 15.06.13 http://www.rapidis.com/products/traffic-analyst/.
6. Trans-Tools. Description and practice use of the Trans-Tools model. In Report WP4. 2006. Date views 15.06.13 http:// www.google.ru/ search?q=TREN+/+04+/+FP6SSP+/+S07.31816+/+502644&hl=ru&newwindow=1&prmd=ivns&filter/.
7. Worldnet: European transport network model refinement regarding freight and intermodal transport to and from the rest of the world. Date views 15.06.13 http://www.transport-research.info/ web/ projects/ project_details.cfm?id=28315/.
8. Rodrigue, J.P., 2012. The geography of transport systems. Hofstra University, Department of Global Studies & Geography. Date views 15.06.13 http:// people.hofstra.edu/ geotrans/.
9. Zhu, Q. and Y. Li, 2008. Hierarchical lane-oriented 3D road-network model. International Journal of Geographical Information Science, 22(5): 479-505.
10. Kotikov, Ju. G. and K.A. Savchenko, 2010. 3D-modeling of multi-level transport interchanges on the basis of the platform ArcGIS. ArcReview, 55: 16-18.
11. Kotikov, Ju. G., 2009. Developing a transport-logistics geodetic databases for a large city on the basis of GIS ArcGIS. Bulletin of Civil Engineers, 2(19): 46-50.
12. Kotikov, Ju. G., 2012. Geoinformation system ArcGIS as an integrator in the models for planning transport systems of large cities. Bulletin of Civil Engineers, 2(31): 214-222.
13. Kotikov, Ju. G. and N.E. Ollova, 2008. Modernization of the transport network using GIS. ArcReview, 46: 18-19.
14. OD cost matrix analysis. Date views 15.06.13 http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/OD_cost_matrix_analysis/00470000004r000000/.
15. Bert, E., 2009. Dynamic urban origin-destination matrix estimation methodology. Thèse No. 4417, École Polytechnique Fédérale De Lausanne (EPFL). Date views 15.06.13 http:// biblion.epfl.ch/ EPFL/ theses/ 2009/ 4417/ EPFL_TH4417.pdf/.
16. Kotikov, Ju. G., 1995. Developing methods for a system analysis and imitational modeling of road objects and vehicles. Dissertation. Institute of Civil Engineering, Leningrad, RU.
17. Heinzle, F., K.H. Anders and M. Sester, 2005. Graph based approaches for recognition of patterns and implicit information in road networks. Date views 15.06.13 http:// icaci.org/ files/ documents/ ICC_proceedings/ ICC2005/ htm/ pdf/ oral/ TEMA9/ Session%204/FRAUKE%20HEINZLE.pdf/.
18. Transport in Beijing. Date views 15.06.13 http:// en.wikipedia.org/ wiki/ Transport_in_Beijing#Road_network/.
19. Samuelsson, H. and S. Kumar, 2004. Ring road NoC architecture, Jonkoping, Sweden. Date views 15.06.13 http://hem.hj.se/~kush/publications/2004/Henrik.pdf/.
20. Ieromonachou, P., S. Potter and J.P. Warren, 2006. Norway's urban toll rings: Evolving towards congestion charging? Transport Policy, 13(5): 367-378.