UDC 656.11

TOPOLOGICAL ANALISIS OF EFFICIENCY OF TRANSPORTATION NETWORK (AT THE EXAMPLE OF LVIV CITY)

Zhuk Mykola, Pivtorak Halyna
Lviv Polytechnic National University,
Stepana Bandery street, 12, Lviv, 79013

The transportation network can be represented at graph. An efficiency indexes for transportation network are global efficiency, local efficiency, transport performance and cost in a graph. Calculation of these indicators was carried out for the Lviv transport terminals network.

The transportation networks are a typical example of spatial networks. Transportation networks are structures that convey energy, matter or information from one point to another [1]. In world practice, the definition of the efficiency of transport networks is carried out in three directions: based on network topology, based on geometric properties of the network, on the basis of an account of network flows. Topologically the network is represented as a graph. The graph of the network consists of nodes and edges.

In terms of topology, the most common indicator is the global efficiency [2]:

$$E = \frac{1}{N(N-1)} \sum_{i \neq j} \frac{1}{l(i,j)} \tag{1}$$

where N - number of nodes in the network;

$l(i,j)$ - the shortest path length between two generic points i and j (physical distances or number of connect).

If we remove one node from the network we will get a subgraph. The subgraph index is a local efficiency. The local efficiency of the network define as the average efficiency of the local subgraphs. The local efficiency also reveals how much the system is fault tolerant (FT).

The minimum number of links to connect N nodes is $E = N - 1$ and describe the tree network. We can also look for the tree which minimizes the total length given by the sum of the lengths of all links – the minimum spanning tree (MST). But of view of transportation, the tree is not a very efficient network and usually more edges are added to the network, leading to an increase of accessibility but also to an increase of a total length. In accordance, the efficiency or the transport performance of the network is defined as the total minimum network length normalized to the minimum spanning tree [3]:

$$P = \frac{\langle l \rangle}{\langle l_{MST} \rangle} \tag{2}$$

where $\langle l \rangle$ - the minimum distance between all pairs of nodes in the network;

$\langle l_T^{MST} \rangle$ - the minimum distance between all pairs of nodes in the minimum spanning tree.

Also, the topological efficiency is determined on the basis of the "cost" network indicator [4]:

$$Cost = \sum_{i,j} a_{ij} \cdot l_{ij} \tag{3}$$

where a_{ij} - presence (1) or absence (0) connect between nodes i and j;

l_{ij} - the length of the link between nodes i and j.

The actual "cost" of the network is compared with the cost of the Minimum Spanning Tree $Cost^{MST}$ and the cost of Greedy Triangulation $Cost^{GT}$:

$$Cost_{rel} = \frac{Cost - Cost^{MST}}{Cost^{GT} - Cost^{MST}} \quad (4)$$

More efficient networks have relative costs near 1, while less efficient networks are closer to 0.

Urban transport network are including city transport network and public transit network pattern. Public transit network pattern are including railway stations, bus stations, airports and external highways.

The network of external transport hubs of Lviv city are including three railway stations, six bus stations and airport. One of a bus station is combined with Main Railway Station, others are located on the main entrance highways. If between two nodes is a direct public transport route then it is considered that between two nodes is an edge.

The results of the formulas (1) - (4) calculations are presented in table 1.

Table 1

The value of the main indicators of the network of external transport hubs in Lviv

The names of indicators	The calculation of indicators	
	topology	distance
Number of nodes	9	-
Number of edges	20	-
Global efficiency of network	0,387	0,08
Local efficiency of network	0,386	0,08
Minimum spanning tree	8	42,9
Greedy Triangulation	35	233,2
The total length of the network	20	131,9
Transport performance	2,5	3,07
"Cost" of the network	0,468	0,444

The significance of global and local efficiency is very close to that of the «small-world networks» and indicates a high level of fault tolerant. Namely, the lack of communication with any of the nodes will not have a significant effect on the ability to interconnect the rest of the nodes of the network under consideration. The greater value of transport performance, calculated on the basis of network distances, in comparison with the topological, indicates the uneven length of the individual edges of the graph.

Literature:

1. Structural Analysis of Transport Network [Електронний ресурс] – Режим доступу до ресурсу: http://shodhganga.inflibnet.ac.in/bitstream/10603/155118/11/11_chapter%204.pdf.

2. Vito Latora, Massimo Marchiori. Effcient behavior of small-world networks. Physical Review Letters, Vol.87, N. 19, 2001. Pp. 1 – 4. DOI: https://doi.org/10.1103/PhysRevLett.87.198701.

3. Barthélemy, Marc. Spatial Networks. Physics Reports, Vol. 499, Issues 1 - 3, 2011. 101 p. DOI: 10.1016/j.physrep.2010.11.002.

4. Rodrigue J.-P. The Geography of Transport System: Fourth Edition. – New York: Routledge, 2017. 440 p.