Structural Analysis of the Pomeranian Metropolitan Railway Transport Network

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Public transport is one of the most important elements in the development of the economy and the social space in which it is located. Therefore, it is very important for the area to properly organize and plan a smooth and fault-tolerant transport network that will facilitate transport in the area. The paper analyzes the structural - using graph theory - railway network of the Pomeranian Metropolitan Railway to assess its structure in terms of its organizational and functional application. This network is used, inter alia, to co-implement public transport within the Tri-City and Kashubia.

Keywords: public transport, rail transport, transport networks, Pomeranian Metropolitan Railway.

1. INTRODUCTION

Public transport within agglomerations is currently one of the most important problems affecting the development of the given area. The increasing congestion in cities causes that the current urban centres in order to increase the standard of living and ensure urban development and its surrounding need to take measures to improve transport in their area, mainly using public transport, which is quite an important element of the policy of Sustainable Transport of European Union [16]. The assumptions of this policy provide for a permanent increase in the role of public transport in exchange for individual transport, which is used in a very ineffective way (the average of passenger car capacity is only 1.3 persons [17], which is a very bad result). This approach is intended not only to reduce congestion in cities, but also to increase the comfort and environmental performance of urban and adjacent areas. Bus transport is currently the most commonly used form of public transport, which unfortunately also has a number of negative attributes (including travelling the same roads as individual transport, noise generation and high environmental pollution). Popular forms of public transport include rail transport (rail and tram). A very good and frequently used solution in the world is the use of rail transport for collective transport in the agglomerations and adjacent areas (e.g. overground railway in largest cities in the USA). The elements that make railway transport so popular, among others, include high transport capacity, punctuality and safety and what is important in these days, quite decent comfort of travelling (using modern fleet).

At present, in Poland, after several decades of railway transport decline (also in the agglomeration and urban areas), it has been re-used to make journeys within agglomerations and in urban and rural areas. Agglomeration networks or urban networks are being built or are being rebuilt in every major agglomeration or conurbation in Poland.

The network of this type was also established in the Pomeranian region in the Tri-City area and Kashubia in the form of the Pomeranian Metropolitan Railway.

The aim of this paper is to make structural analysis - using graph theory - of the Pomeranian Metropolitan Railway network in order to evaluate its structure from the organizational and functional perspective.

The article has been divided into 5 parts, the first one being a short presentation of the discussed rail network. In the next ones, the fundamentals of graph theory used for network analysis, among

others transport networks, have been presented, as well as the analysis of the network and the results of the research. The last chapter summarizes the results and presents conclusions of the analyzed network.

2. POMERANIAN METROPOLITAN RAILWAY

Pomeranian Metropolitan Railway (PMR) is a company which was established by the regional government of the Pomeranian Voivodeship in order to improve public transport in the Tri-City and Kashubia [20]. It is a significant fact that PMR was established as an investment independent of the main railway provider in Posland, i.e. PKP PLK S.A. The Pomeranian Railway was fully financed from funds of the regional government of the Pomeranian Voivodeship. According to the data provided by the company which at first built the railway line and later became its manager, the line currently has 31 stops and is divided into four routes:

1) agglomeration: Gdańsk Wrzeszcz – Gdańsk Osowa – Gdynia Główna,

three regional routes:

2) Gdańsk Główny – Kartuzy,
3) Kościerzyna – Gdańsk Osowa – Gdynia Główna,
4) Kościerzyna – Gdańsk Wrzeszcz – Gdynia Główna [18].

The scheme of the railway line is shown in Figure 1.

In order to evaluate the structure of the Pomeranian Metropolitan Railway network in terms of organizational and functional aspects, the structural network presented in Figure 1 was analyzed - as a transport network - in terms of its parameters. For this purpose, the theory of graphs was used.

3. METHODOLOGY OF CONDUCTED RESEARCH

Graph theory is often used to analyze different types of networks. First of all, it is used for the analysis of social networks [1, 2, 8], however some positive results it has brought in the field of social sciences, as well as the development of mathematical methods associated with it, have led to its use in carrying out effective neuron [3, 4, 11, 12] and biological [10] network analysis. The possibilities of analysis using the graph theory described above have also been presented in [7]. The theory of graphs, in addition to the typical natural network, is also used to analyze artificial networks created by humans such as computers [5, 14] and, what is important for the following study, to analyze transport networks [6, 7, 9, 13, 15] . Graph theory enables to evaluate transport networks from an organizational and functional perspective. Most of the measures and calculations applied provide us also with the opportunity to get an indication of which of the points of the network are the main players that are the centre of the network being analyzed. The article uses the indicators described, among others in [7, 13] (due

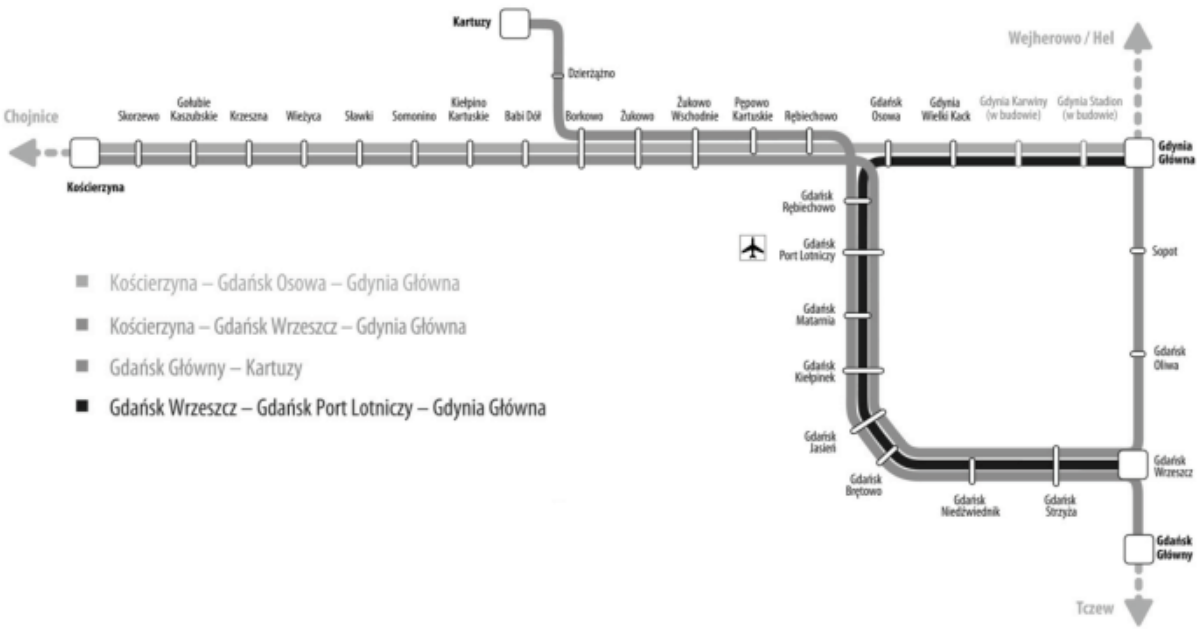

Fig. 1. The scheme of the Pomeranian Metropolitan Railway [21].

to the limited volume of the article the mathematical basis of the indicators has not been presented but can be found in the bibliography). The most commonly used indicators include:

1) Normalized degree dc_i *i*-th network node.

1The greater the value of the dc_i index for the i-th node, the node is more important in the network or closer to its centre.

2) Eccentricity ec_i *i*-th network node.

The lower the value of the ec_i index for the i-th node, the node is more important in the network or closer to its centre.

3) Radius rc_i *i*-th network node.

The greater the value of the rc_i index for the i-th node, the node is more important in the network or closer to its centre.

4) Closeness cc_i.

5) Betweenness bc_i *i*-th network node.

The greater the value of the bc_i index for the i-th node, the node is more important in the network or closer to its centre.

6) Clusterization gc_i *i*-th network node:

The greater the value of the gc_i index for the i-th node, the more important the node is in the network, or closer to its centre.

Calculating the value of the above indicators allows to evaluate the relation between the different nodes in the network, as well as to determine which type of network we are dealing with, and which one or which of the nodes in the network play a dominant role. There are practically no situations in the networks when all nodes have the same degree of "importance".

Each network has some key nodes that are responsible for the proper functioning of the entire network, to a higher extent than the other ones. Determining these nodes and their locations allows to draw conclusions about the current state of the network.

4. RESULTS OF THE ANALYSIS

On the basis of Fig.1, a scheme of the transport network of the Pomeranian Metropolitan Railway was drawn up and shown in Fig. 2.

Fig. 2. Network layout of Pomeranian Metropolitan Railway.
Source: Own study based on Fig. 1. using Gephi software.

As shown in Figure 2, the network layout is made up of 31 interrelated nodes that correspond to the layout of the Pomeranian Metropolitan Railway. Figure 2 shows the stations appearing in the diagram developed by the carrier.

For the obtained network, the parameters described in Chapter 3 have been calculated and the results of the calculations are shown in Table 1.

Based on the results of the calculations presented in Table 1, it was found that Babi Dół, Borkowo, Gdańsk Airport and Żukowo and Żukowo Wschodnie stations are the main nodes of the Pomeranian Metropolitan Railway. Figures 3 and 4 show graphically the distribution of sample, calculated network coefficients - the larger the diameter of the circle and the darker it is in colour, the higher the coefficient value for the node is. The data visualization has been done using Gephi software.

Table 1. Indicators for each network node.

City (node)	*node degree* k_i	*Normalized degree* dc_i	*Eccentricity* ec_i	*Radius* rc_i	*Closeness* cc_i	*Betweenness* bc_i	*Clusterization* gc_i
Babi Dół	4	0.1333	9	0.1111	0.1887	0.4046	0
Borkowo	6	0.2	9	0.1111	0.2055	0.5218	0
Dzierżążno	2	0.0667	10	0.1	0.1734	0.0667	0
Gdańsk Brętowo	4	0.1333	15	0.0667	0.1596	0.0337	0
Gdańsk Główny	1	0.0333	17	0.0588	0.1339	0	0
Gdańsk Jasień	6	0.2	14	0.0714	0.1863	0.2854	0
Gdańsk Kiełpinek	6	0.2	13	0.0769	0.2041	0.3130	0.3333
Gdańsk Matarnia	4	0.1333	13	0.0769	0.1935	0	1
Gdańsk Niedźwiednik	4	0.1333	16	0.0625	0.1471	0.0092	0
Gdańsk Oliwa	2	0.0667	17	0.0588	0.1415	0.0457	0
Gdańsk Osowa	4	0.1333	14	0.0714	0.1786	0.1467	0.3333
Gdańsk Port Lotniczy	6	0.2	12	0.0833	0.2239	0.4478	0.1667
Gdańsk Rębiechowo	4	0.1333	13	0.0769	0.1987	0.1006	0.3333
Gdańsk Strzyża	6	0.2	15	0.0667	0.1695	0.1874	0
Gdańsk Wrzeszcz	5	0.1667	16	0.0625	0.1538	0.1414	0
Gdynia Główna	3	0.1	16	0.0625	0.1500	0.0732	0
Gdynia Wielki Kack	4	0.1333	15	0.0667	0.1622	0.1077	0
Gołubie Kaszubskie	4	0.1333	15	0.0667	0.1075	0.1287	0
Kartuzy	1	0.0333	11	0.0909	0.1485	0.0000	0
Kiełpino Kartuskie	4	0.1333	10	0.1	0.1724	0.3701	0
Kościerzyna	2	0.0667	17	0.0588	0.0896	0	0
Krzeszna	4	0.1333	14	0.0714	0.1181	0.1862	0
Pępowo Kartuskie	4	0.1333	12	0.0833	0.1987	0.1180	0
Rębiechowo	4	0.1333	13	0.0769	0.1887	0.0996	0.3333
Skorzewo	4	0.1333	16	0.0625	0.0980	0.0667	0
Sławki	4	0.1333	12	0.0833	0.1429	0.2874	0
Somonino	4	0.1333	11	0.0909	0.1571	0.3310	0
Sopot	2	0.0667	17	0.0588	0.1402	0.0422	0
Wieżyca	4	0.1333	13	0.0769	0.1299	0.2391	0
Żukowo	6	0.2	10	0.1	0.2158	0.4966	0
Żukowo Wschodnie	6	0.2	11	0.0909	0.2239	0.5287	0

Source: Own study based on Fig. 2. using Gephi software.

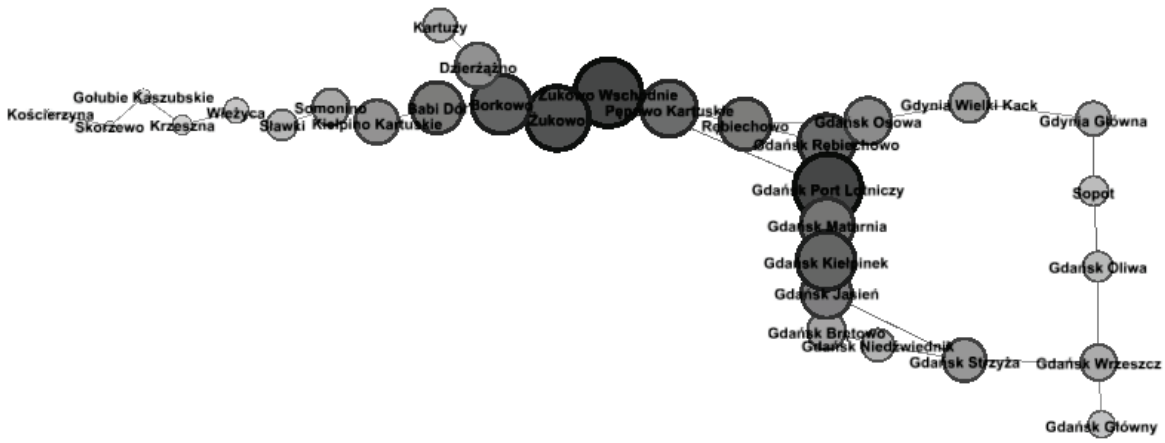

Fig. 3. Closeness of the analyzed Pomeranian Metropolitan Railway network.
Source: Own study using Gephi software.

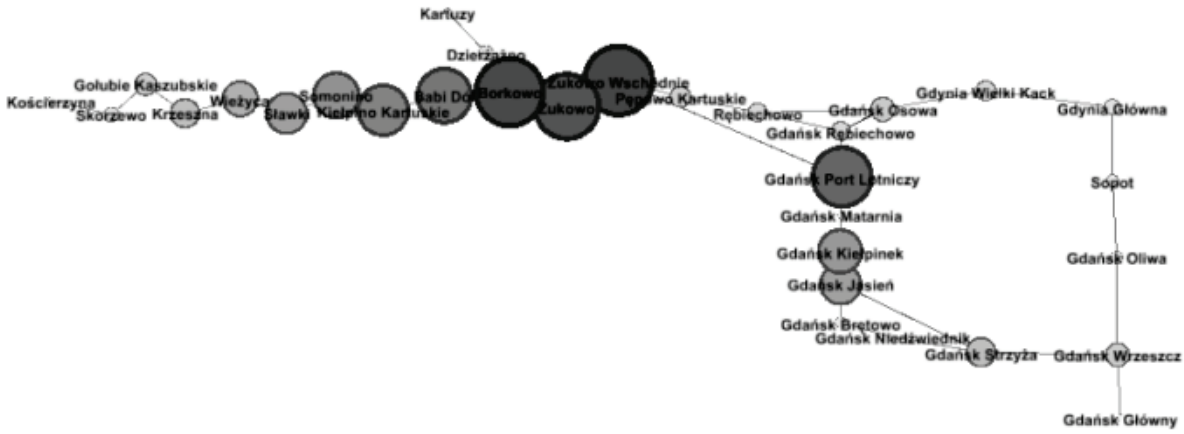

Fig. 4. Betweenness of analyzed Pomeranian Metropolitan Railway network.
Source: Own study using Gephi software.

Then, calculations were made for a network consisting only of nodes and endpoints (intermediate stations have been omitted). A network consisting of nodes and endpoints only is shown in Figure 5.

Table 2 shows the results obtained for a network that includes node and end stations only.

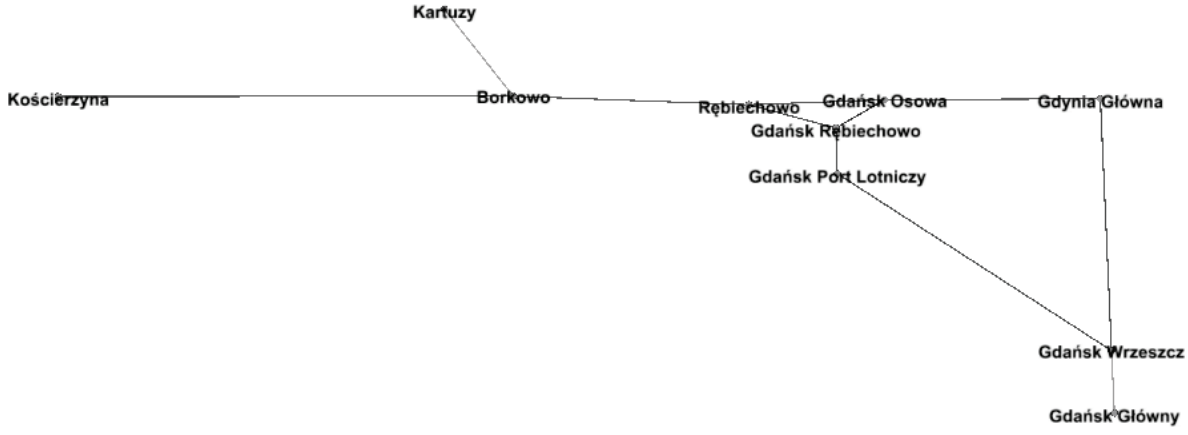

Fig. 5. Scheme of Pomeranian Metropolitan Railway including nodes and network endpoints only.
Source: Own study based on Fig. 2. using Gephi software.

Table 2. Indicators for a network that includes node and end stations only.

City (node)	*node degree* k_i	*Normalized degree* dc_i	*Eccentricity* ec_i	*Radius* rc_i	*Closeness* cc_i	*Beetweeness* bc_i	*Clusterization* gc_i
Borkowo	6	0.6667	5	0.2	0.4091	15	0
Gdańsk Główny	1	0.1111	6	0.1667	0.2813	0	0
Gdańsk Osowa	4	0.4444	3	0.3333	0.5000	5.8	0.3333
Gdańsk Port Lotniczy	6	0.6667	4	0.25	0.4286	9.2	0
Gdańsk Rębiechowo	6	0.6667	3	0.3333	0.5	12.2	0.3333
Gdańsk Wrzeszcz	5	0.5556	5	0.2	0.3750	9	0
Gdynia Główna	3	0.3333	4	0.25	0.4286	2.8	0
Kartuzy	1	0.1111	6	0.1667	0.3000	0	0
Kościerzyna	2	0.2222	6	0.1667	0.3000	0	0
Rębiechowo	6	0.6667	4	0.25	0.5000	18	0.3333

Source: Own study based on Fig. 2. using Gephi software

As shown in Table 2, for the network consisting only of nodes and end stations, Borkowo and Gdańsk airport are also the most important stations. The analysis of the network which took into account the endpoints and node stations only has also revealed quite significant role of Rębiechowo and Gdańsk Rębiechowo stations in the analyzed network.

Figures 6 and 7 show graphically the distribution of sample, calculated network coefficients, for networks that include endpoints and nodes only - the same as before, the larger the diameter of the circle and the darker its colour, the higher the value for the node is.

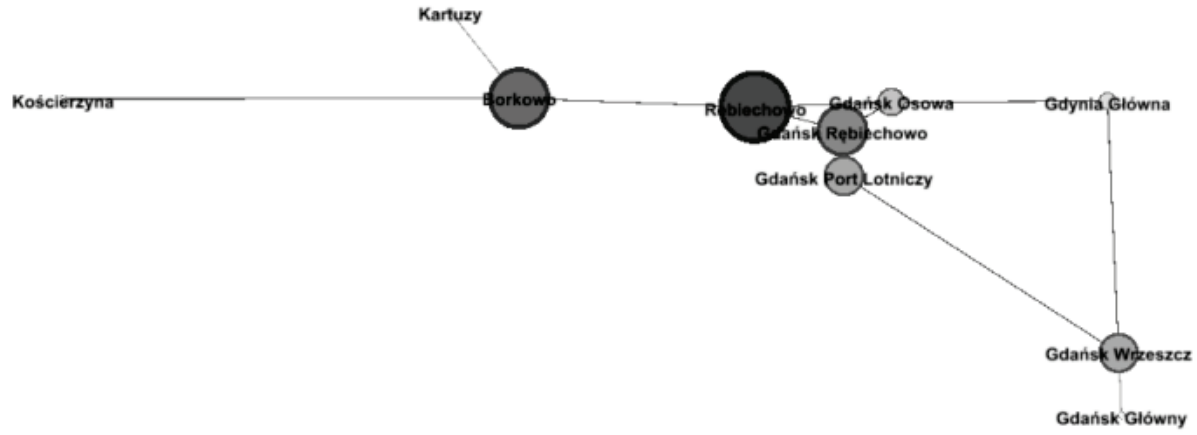

Fig. 6. Closeness of the analyzed Pomeranian Metropolitan Railway network that includes endpoints and nodes only.
Source: Own study using Gephi software.

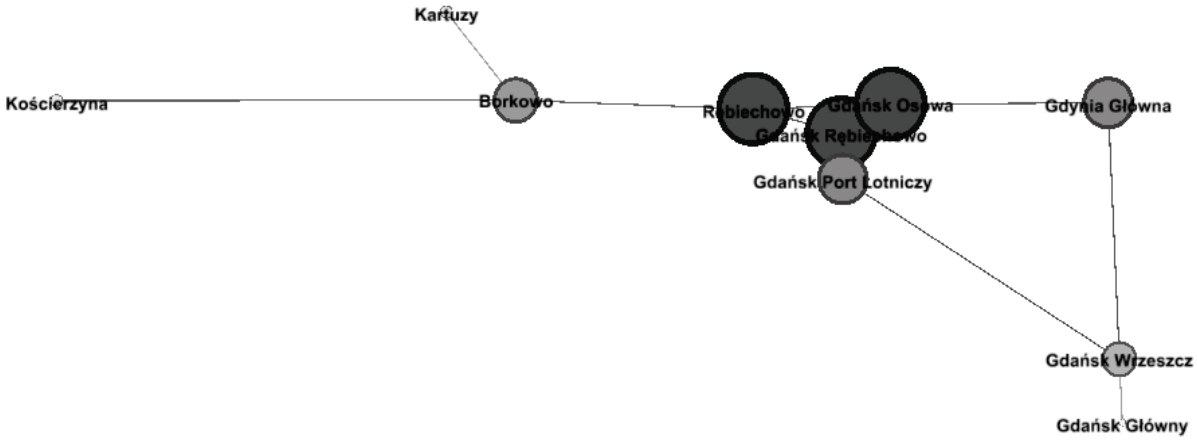

Fig. 7. Betweenness of the analyzed Pomeranian Metropolitan Railway network that includes only endpoints and nodes.
Source: Own study using Gephi software.

5. SUMMARY

The analysis of the Pomeranian Metropolitan Railway showed that the network does not have one central node but several ones. What is important, the key nodes of the network are not the main stations of the Tri-City (Gdańsk Główny and Gdynia Główna), but the stations such as Gdańsk airport, Babi Dół, Rębiechowo and Gdańsk Rębiechowo.

Due to the great importance of Rębiechowo and Gdańsk Rębiechowo stations (which showed very good analysis for the network considering only intermediate and final stations), the author believes that the carrier should consider stopping at these train stations trains which go on the Kościerzyna -

As shown in Table 1 and 2, the stations of Babi Dół, Gdańsk airport, Rębiechowo and Gdańsk Rębiechowo are very important for the analyzed network. As a result, the Pomeranian Metropolitan Railway should take particular care of the above stations.

Gdańsk Wrzeszcz - Gdynia Główna route. Such connections can make the network more attractive for passengers by making it more accessible for them.

Information and statistics presented on the site of the carrier clearly show that the network is becoming increasingly important in the agglomeration transport system [19], primarily as the means of public transport for intra-agglomeration.

This is a very important conclusion (network layout complies with folded objectives of the network) and the situation (increasing number of passengers), to be in line with the objectives of the creation of the Pomeranian Metropolitan Railway, whose main task was to improve transportation between the Gdańsk Airport and internal transport system of the Tri-City and Kashubia [20].

The analysis and statistical data presented by the provider indicate that the goal of the network has been achieved to a large extent.

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