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SPECIFICATION OF A LOCATION FOR OPTED PORT LOGISTICS CENTER IN A GIVEN AREA USING THE METHOD OF OPERATIONAL RESEARCH

Summary. This paper is focused on area identification to find a proper location for the specific port logistic center in a certain territory by applying the particular method of operational research. Graph theory offers a useful tool for solving such problems in transportation infrastructure development. The type of the network optimization technique depends on problem definition. In the first chapter, we have explained some of the algorithms often applied for similar purposes. In this case, the focus is on Minimum Spanning Three algorithm. Based on well-known Prim's and Kruskal's algorithms, some modifications are introduced, to improve the processing speed and memory consumption. The next four chapters describe individual parameters, perspectives, requirements, and financing details for building new combined transport terminals as well as a planned port logistics center. The subsequent, the most important, chapter presents the model example for specifying the proper location of a given port logistics center when using the method of operational research.

1. INTRODUCTION

In the near future, a multimodal logistics center at the river of Labe near Pardubice should become part of a network of logistics centers in the Czech Republic and also in Europe. The connection to the European waterway network, the connection to the transit railway corridor, and the connection of Pardubice to the motorway network of the Czech Republic are supporting arguments for the location a logistics center in Pardubice.

The support for the territorial development of the designated zone from the level of the state administration (Ministry of Transport and the Directorate of Waterways), the optimal distance to the East Bohemian Airport (EBA), and ecological benefits for the environment are also other positive reasons for the location of logistics center in Pardubice. The planned logistics center will have a total area of 68.71 ha and will included the territorial plans for the city of Pardubice and the municipality of Srnojedy [1, 2].

2. GRAPH THEORY AND NETWORK OPTIMIZATION

For optimal transport connections, we can represent the problem as the Traveling Salesman Problem (TSP) or Minimum Spanning Tree (MST), well known from the graph theory, as the most popular network optimization techniques. These tools are useful to optimize the connections between each vertex in the graph and potential port logistic center.

All graphs represented in this article are finite, simple, and connected. The system of traffic routes can be transformed into a graph, where vertices represent destinations (towns or cities), edges represent transport infrastructure, and weights of edges represent the energy consumed to drive the transport mean (ship, car, aero-plain, train, or something else) between two destinations. To model this situation, we create a connected graph $G = (V, E)$ with weighted edges.

For the application of MST or SPT algorithms, first we have to create a modified adjacency matrix, which we call "Weighted Adjacency Matrix". This matrix is similar to the Adjacency Matrix where in positions of elements of the matrix are either 1 or 0 if there is an edge between vertices v_i and v_j or not. In this modified Weighted Adjacency Matrix, the positive number w_{ij} on the position of the element v_i and v_j indicates the weight of the edge connecting vertices v_i and v_j, if the edge between vertices v_i and v_j exists; $i, j = 1, ..., N$. Some of v vertices represent potential logistic centers. Distances between them are not important, so we can set $w_{ij}=\infty$. A value of ∞ indicates that there is no edge between vertices v_i and v_j [3, 4].

Weighted Adjacency Matrix is thus a square matrix $W = n \, x \, n$, where n denotes the number of vertices and the value of the element at the position w_{ij} corresponds to the weight of the edge between vertices v_i and v_j. Weighted Adjacency Matrix is usually symmetric with respect to the main diagonal. The diagonal elements have a value of 0, so the algorithm uses only the elements of the triangle above the main diagonal; see Fig. 1.

	v_1		v_i		v_j		v_n
v_1	0		w_{1i}		w_{1j}		w_{1n}
		0					
v_i			0		w_{ij}		w_{in}
				0			
v_j					0		w_{jn}
						0	
v_n							0

Fig. 1. An example of Weighted Adjacency Matrix

The shortest path is formulated as a task with a given set of ports and the routes between them, from start to the end point. In this paper, the main task is to find the shortest (most economical) route passing from each destination to potential port logistic center and return. Efficient optimization techniques are based on well-known algorithms for the shortest path calculation as Dijkstra's or Floyd's algorithm [5]. Today, we have many applications of them in many programmable tools.

Here we mostly discuss about single-commodity transportation problem, but in cargo transport we often need multi-commodity approach, which is more complex. Moreover, linearity of transport costs is not present in practice so often, so non-linear problems could be more demanding.

The optimal traffic connections from all ports (towns and cities) to potential logistic center are represented by the spanning tree of the graph in the shape of tree/star configuration; see Fig. 2.

The problem to find out the opted port logistic center is in firm correlation to the cheapest traffic system, so it means that we must find out the minimum spanning tree.

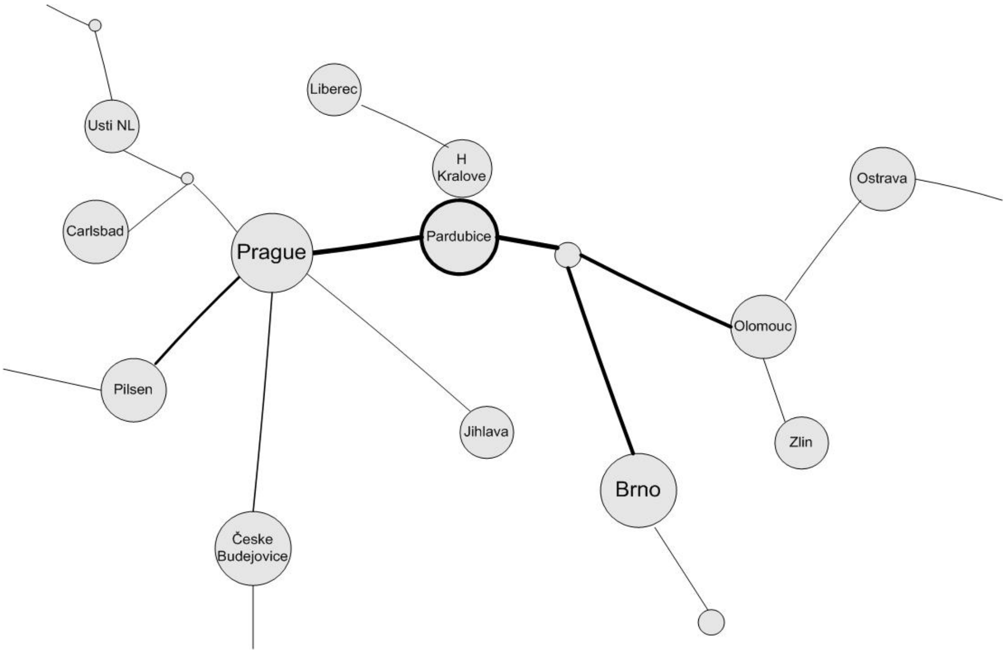

Fig. 2. Solution of the Minumum Spanning Tree for Czech Republic railway systém
Source: authors

The spanning tree of a connected graph G is a sub-graph G' which connects all vertices and which does not contain any cycles. The minimum spanning tree is denoted as $T = (V, E')$, where $V' = V$ and E' is the set of $n - 1$ edges of the minimum spanning tree, and it applies that $E' \subseteq E$. The sum of the weights of edges of MST is minimal. The spanning tree $T_1 = (V, E_1)$ of the graph G we call the Minimum Spanning Tree (MST) if for each other spanning tree $T_2 = (V, E_2)$ of the graph G it holds that: $w(T_1) \leq w(T_2)$.

For searching the minimum spanning tree, there are several well-known algorithms that search for the MST in different ways. For example, the Kruskal's algorithm, Prim's algorithm, or Borůvka's algorithm are generally well-known. In the article, we use some similar principles of mentioned algorithms for searching the MST [6,7], but we use some modifications based on Weighted Adjacency Matrix. That matrix is symmetric with respect to the main diagonal; the diagonal elements have a value of 0, so the algorithm will only use the elements of the triangle above the main diagonal. In implementation, we apply a new approach, starting the procedure from the edge with minimal weight. We search through the elements of the matrix and find the one with the smallest positive value w_{ij}. It means that edges i and j are the parts of MST. Denote chosen matrix element in bold and underlined, then delete the rows v_i, v_j and columns v_i, v_j. If there is more than one element with the same smallest positive value, we have to choose arbitrary one of these, as more MST solutions exist. So we repeat that procedure to the last edge. So in that way, the spanning tree can be non-connected during the procedure. It is alike the Kruskal's algorithm. Finally, we have a connected tree. Constantly we have to take care not to close the loop. We can ensure it by eliminating (deleting) all weights from Weighted Adjacency Matrix that are in positions, where newly marked row and column intersect with rows and columns previously marked [7]. Main difference from the Kruskal's algorithm is that we do not form the list of weights in ascending or descending order.

For tree/star shape of the network we have trivial procedure based on the MST calculation, to sum all distances from each location to the potential port logistic center, looking for the minimal value.

Generally we can say that weights between two edges are in firm correlation to distances (lenght) but not only with that. For example, each vertex (location) has different transportation strenght, so we call it "weight of vertex". Sometime we have a situation where distances in both directions are different, A – B not equal to B – A, but it s not the case in this research.

Moreover, the weight of edges can be the result of many elements e.g., transport capacity of infrastructure between destinations (towns or cities). Moreover, we have to multiply each weight of edge in respect to their transport importance, that is in relation to their traffic amounts. We call it "weight of vertex", see formula 1.

3. REQUIREMENTS FOR THE COMBINED TRANSPORT TERMINALS CONSTRUCTION

The implementation of the new combined transport terminal (CTT) construction is a challenging task. In the current network of privately owned terminals, building the new capacities from public budgets would lead to duplication of services in many places. Creating new capacities would pose a threat to the investment of owners of current terminals. According to some studies [8,9], construction of new terminals from the state public budgets is not real in the current period. The reason consists in the possibility of threatening private investment and the emergence of litigation which could stop or totally thwart the entire investment planning. The current terminal network layout, which relies on the most important industrial nodes on railway infrastructure and strong industrial centers, is the problem as well [8,10,11].

The possibility of further constructions of new combined transport terminals will be realized with respect to the existing terminal network. The location and ownership base of each operated terminal is the basic parameter for specifying the new terminal location. The basic relations of terminals on the territory of the Czech Republic are as follows (see Fig. 3) [8, 10].

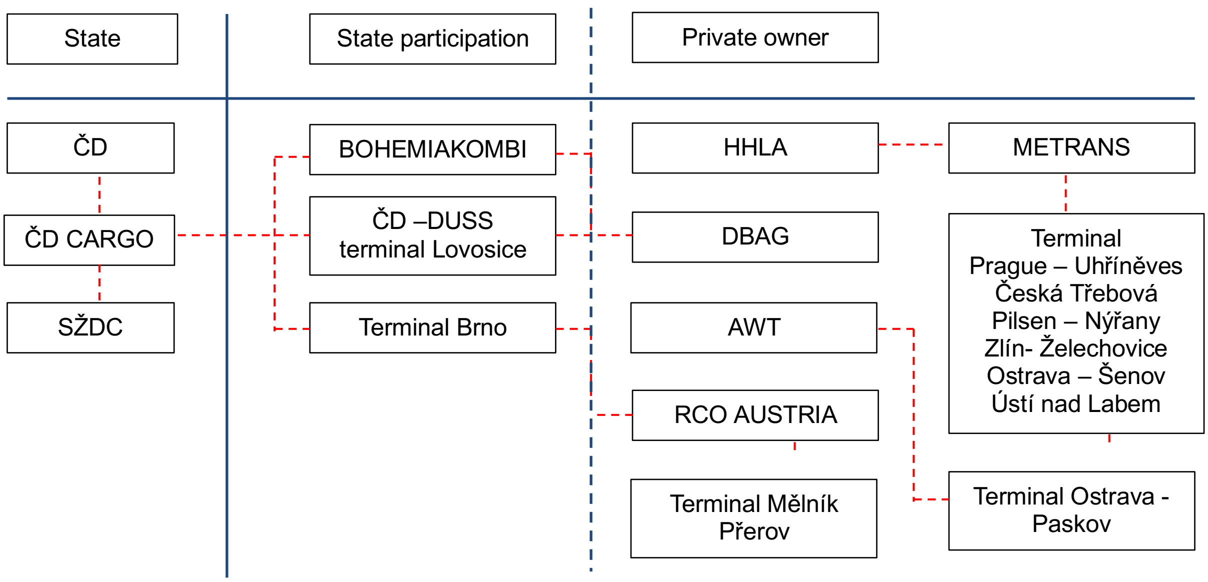

Fig. 3. Ownership structures of terminals in the Czech Republic
Source: authors

Fig. 3 shows the property rights of individual entities operating in combined transport in the territory of the Czech Republic. There is a certain degree of state participation in the operation of this transport, including the participation of individual foreign entities [8, 9, 12]. Geographic layout of the current infrastructure is another factor determining the possible construction of new terminals. Existing and operated terminals are located on major railway corridors and close to major industrial centers in the Czech Republic. The position of each terminal is shown below (see Fig. 4).

4. FINANCING THE COMBINED TRANSPORT TERMINAL CONSTRUCTION

According to some authors [9,10], the actual construction of combined transport infrastructure is performed only within private entities in the foreseeable future in the Czech Republic. State institutions have not been preparing any major terminal building project or a network of free public access logistics centers yet.

In the near future, the state will be limited to partial incentives for individual private entities under subsidies and development of operational programs. Emphasis will be put on the development of the terminal infrastructure and the reduction of the environmental demands of individual processes. The Czech Republic and the EU are on the way to shift road transport performance to rail transport, and from this point of view, combined transport ensures the particular development. The influence of political decisions and preferences of particular modes of transport can be crucial for the future of combined transport in the Czech Republic [2, 11].

Fig. 4 depicts the location of individual terminals on railway infrastructure in the territory of the Czech Republic by red points.

On the territory of the Czech Republic, terminals have been built mostly by private entities, and building must be based on the valid Czech and European legislation. The AGTC Agreement has already been mentioned and supplemented by Regulation (EC) No 913/2010 of the European Parliament and of the Council on a European rail network for competitive freight [13], and Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network – it addresses the European Union's guidelines and objectives for the development of the trans-European transport network, projects of common interest, cooperation with third countries and requirements for rail, aviation, maritime and road transport infrastructure [14]. Each building has to be assessed according to the Environmental Impact Assessment (EIA).

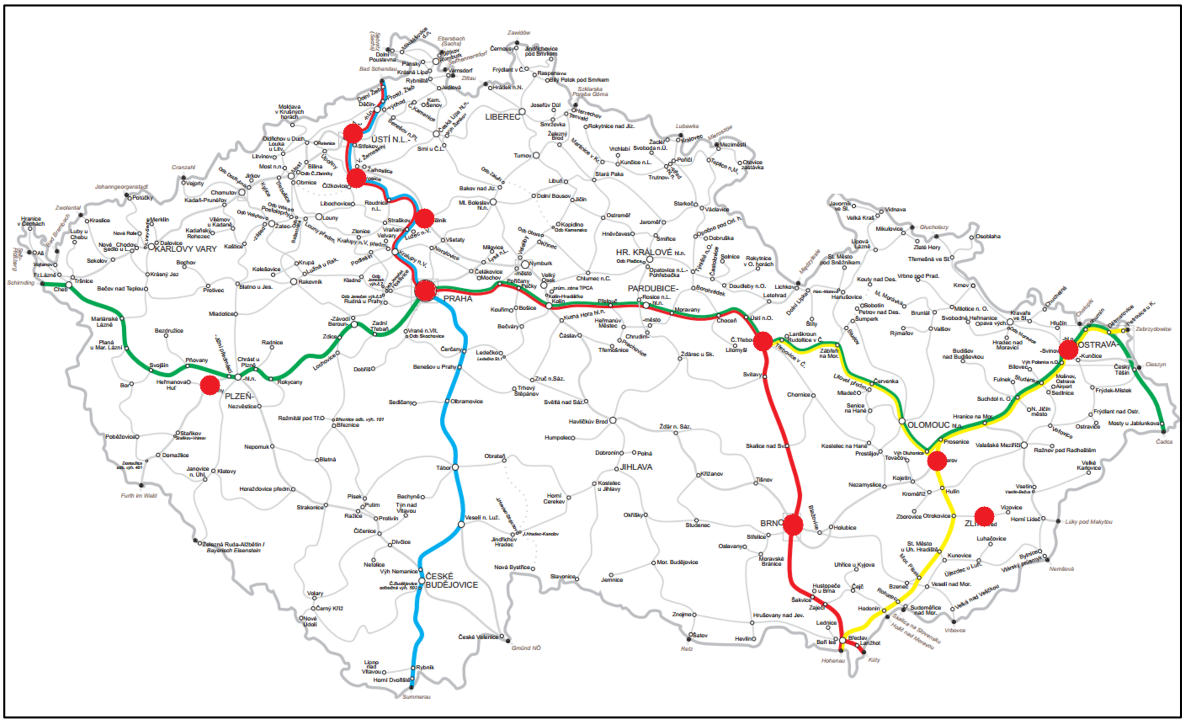

Fig. 4. Map of railway terminals network in the Czech Republic
Source: authors, based on [8, 9, 12]

5. TRANSPORT AVAILABILITY FOR THE PORT LOGISTIC CENTER PARDUBICE

Port logistic center Pardubice will be of a multi-modal character with connection to the following types of transport infrastructure:

- **road network** - D11 motorway with I/37 crossing to Hradec Králové,
- **railway network** - connecting tracks to the railway station Rosice nad Labem located on the railway line Pardubice - Hradec Králové, which is part of the railway network of national importance;
- **waterway network** - the public port of the city of Pardubice located on the left bank of the river of Labe will be a part of this logistics center. However, currently, the navigable stretch of the Labe waterway ends at the port of Chvaletice, and the direct connection of the logistics center to waterway transport is not possible until accomplished construction of the new navigation stage Přelouč; and
- **air network** - Pardubice International Airport will be located south of it, in a distance of 2,600 km from the main part of the logistics center.

Port logistic Center Pardubice will offer logistics activities in a container terminal, a public port, warehouses with goods distribution as well as business activities, light and medium industrial production, without negative effects on the environment.

6. MODEL EXAMPLE OF THE PORT LOGISTICS CENTER PARDUBICE LOCATION

The position of a new terminal (or logistics center) is a significant factor for its construction. Logically, it is proposed to locate the terminal in the Prague Agglomeration area; however, this variant would come into conflict with a number of negative issues, such as the density of the built-up area and the impact on the environment and human health. A particular method of operational research was applied to specify a proper location for the port logistics center Pardubice [15,16].

The aim was to find the location of the terminal (center) to minimize the weighted sum of all distances from the served cities. The number of active entities, which are engaged in transport and storage activities on the territory of individual regions, was selected for the purpose of determining the weights of individual vertices [17]. As for the calculation, the values of distances were determined as the distances among individual cities by rail [18]. To find the vertex with the smallest transport performance, a calculation according to the following formula (1) was performed [16]. Calculations are summarized in Table 1.

$$f\left(D_k^{'}\right) = \sum\sum 2 * d(u,v) * w(u,v) \text{ [-]} \quad (1)$$

where: *d (u,v)* - length of edge (m); *w (u,v)* - weight of vertex (-).

The final location of the center (terminal) in the Prague agglomeration is shown in Table 1. As already stated, the best resulting variant from the calculations is disapproved and the second best variant from the perspective of smallest transport performance is accepted, i.e., the area for the port logistics center will be located in the city of Pardubice [2].

The location of the new combined transport terminal is planned to the left bank of the river of Labe near Srnojedy in the direction of river flow. From the current approach of the administrative authorities to the construction of the port in Pardubice, it is not quite clear where the Labe shore will be located. In 2016, information revealed the construction of the port on the right bank of the river of Labe in the Synthesia site (chemical company). Possible location is depicted in Fig. 5. The variant "A" represents an older concept of the port construction and the variant "B" represents the new construction option [19].

7. CONCLUSION

In this paper, we are looking for a proper location of a specific port logistic center in a certain territory by applying the particular method of operational research. Graph theory offers useful tool for solving such problems. For tree/star shape, we have a trivial procedure based on the MST (Minimum Spanning Tree) calculation, to sum all distances from each location to the potential port logistic center, looking for the minimal value. In this research, we use some of the principles of Prim´s algorithm for searching the MST but we use some modifications based on operations in Weighted Adjacency Matrix. We search through the length elements of the matrix and find the one with the smallest positive value.

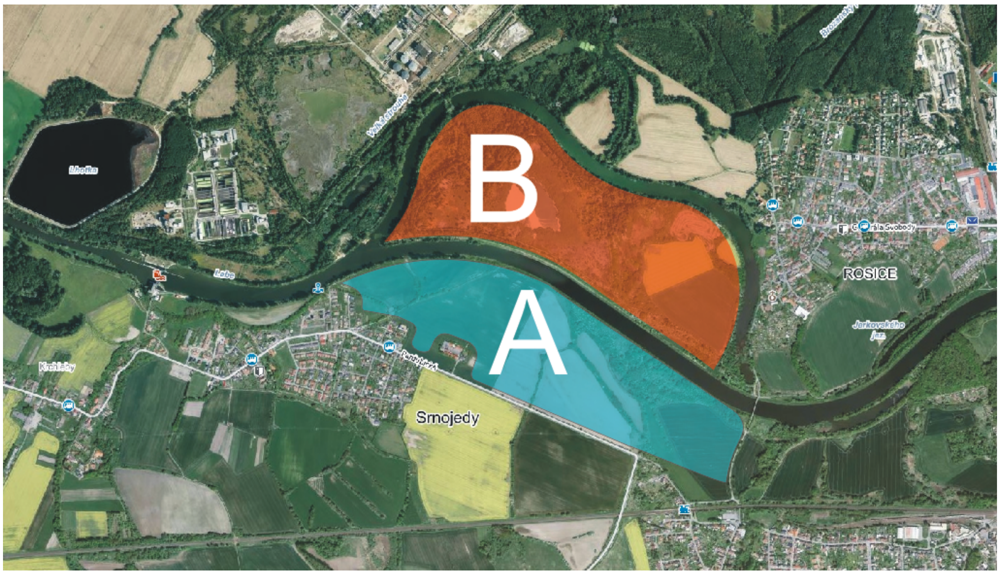

Fig. 5. Variants of the Srnojedy port location
Source: authors, based on [20]

Table 1
Calculation of the variant with the smallest transport performance. Source: authors

Regional cities	Entities	Calculated quantities/1000	Result of the calculation
Prague	7723	7.723	2297.42
Czech Budejovice	329	0.329	5567.042
Pilsen	697	0.697	4850.754
Carlsbad	271	0.271	7853.884
Ústí nad Labem	311	0.311	4542.752
Liberec	386	0.386	5185.65
Hradec Králové	339	0.339	4027.476
Pardubice	287	0.287	3599.994
Jihlava	213	0.213	4522.956
Brno	1451	1.451	6264.344
Olomouc	333	0.333	6390.778
Ostrava	916	0.916	8735.102
Zlín	287	0.287	7726.788

So we repeat that procedure to the last edge. Constantly we have to take care not to close the loop. Based on the calculated MST, we introduced weight of each vertex, respectively on traffic importance. After that we compared all potential positions, to minimize the weighted sum of all distances from the served cities. With such methodology, we made projection of logistic location in Pardubice. The port of Pardubice depends on the completion of the navigational stage in the city of Přelouč and the extension of the Labe fairway from Chvaletice to Srnojedy throughout the section. In addition, it is necessary to modernize the Srnojedy navigation stage to achieve the complete termination of the waterway to the Pardubice Port Logistics Center.

In Fig. 5, the variant "A" is more suitable for a possible future connection of the terminal to the rail network and the variant "B" is located at the site with an occurrence of existing ecological burden after chemical production, which will have to be removed before the construction begins. The modern terminal in the city of Pardubice is also important for the electrical company Foxconn cz, s.r.o. with a connection to components in containers delivery from Taiwan using combined sea/rail transport across the Adriatic ports or the future sea/inland waterways through Hamburg.

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