The Exhaustive Search Algorithm in the Transport network optimization on the example of Urban Agglomeration Rijeka

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Abstract

The paper presents the use of Exhaustive Search Algorithm and model of Traveling Salesman Problem (TSP) in the transport network optimization, on the example of Urban Agglomeration Rijeka. The aim is optimal routing design between cities and municipalities of Urban Agglomeration Rijeka. In creating of Urban Agglomeration Rijeka has been defined the criteria of sustainability of transport and infrastructure systems covering the most important existing and planned economic zones, infrastructure buildings and traffic hubs (rail, highway, port, airport), located in cities and municipalities in the wider Rijeka area.The transport network of Urban Agglomeration Rijeka should provide optimal supply of cities, municipalities, and their distribution centers in the area of agglomeration. Choosing the relevant information technology and computer software to enable us to create optimal node connections (cities, distribution centres, ports, and terminals), and arrange the optimal transportation routes, is the key factor of transportation network modelling for an effective distribution of goods.

Visual and object-oriented methods of modelling and programming allows us to use and visualize the Exhaustive Search Algorithm in the transport network optimization, in the way to identify multiple optimal solutions with a clear interpretation of the results not only of the optimal value but also at approximately equal values and their deviations from the optimal value. Given that Urban Agglomeration Rijeka covers 10 cities and municipalities, Exhaustive Search Algorithm is suitable for designing the transport network. In making the program based on the Exhaustive Search Algorithm have been used Visual Basic for Application in Excel spreadsheet interface. The Exhaustive Search Algorithm, with the calculation of the optimal relation, also allows the calculation of suboptimal relations whose values within an acceptable deviation from the optimal value. The calculation and insight into the more optimum relationships can significantly support the reduction of transport costs, but also the creation of greater opportunities for the carrier with the more flexible design of the structure of goods flows and gaining more profit.

Key words: Transport network optimization, Travelling Salesman Problem, Urban Agglomeration Rijeka, Exhaustive Search Algorithm, optimal and suboptimal relationships

1. Introduction

Due to the large increases in the number of cities in the world, mobility between cities has become difficult because of there existing many dissimilar roads to reach the same city with different travelling cost [2], where there are several places that are all directly connected to each other by different long roads and the passenger wants to make the shortest trip. Some algorithms can be used to guide people using one of the transport or movement methods (walking, train, car, and bus) to reach their destination on the shortest route. [11].

The paper presents the use of Travelling Salesman Problem (TSP) model and a Exhaustive Search Algorithm on the example of the transport network of Urban agglomeration Rijeka The flexibility and adaptability of transport networks can be achieved by optimizing the routes of movement of vehicles between one of the sources and multiple destinations in transport network. [9]. The most important operational decision related to optimizing transport network of Urban aglomeration Rijeka can be set the analogy according to that the number of calculated suboptimal solution.

The basic criterion for selection of optimal transport relation is the distance between cities (trade-transport centres). In cases of the same or similar distance, there is a possibility of dynamic selection of multiple transport relations for different periods of time, so, from the perspective of other relevant criteria, there can be one optimal relation for a certain period of time, and another optimal relation for other periods. The majority of existing software solutions allows calculation and insight into one optimal solution. Using visual and object methods in programming and modelling to form an algorithm of detailed search criteria can simulate models with more than one optimal solution for small scale patterns, with clear interpretation of the results, not only those in optimal value, but also those of approximately equal values and their deviation from the optimum. Finding a large number of optimal transport relations allows greater flexibility in making a multiobjecitive selection of optimal transport relation, especially over diferent periods of time [10].

Methodological frame of use of Visual Basic as a development tool in the visual modelling of Exhaustive Search Algorithm in VBA for Excel can serve as an incentive in creating new highly sophisticated algorithms, which will enable us to compute optimal and suboptimal solutions of transport network [10], [9].

Visual and object oriented methods of modeling and programming in the design of the exhaustive search algorithm in the spreadsheet interface, enables visualisation and interpretation of the transport network solution that can lead to insights into essential transport problem details that were previously not clearly recognizable and may indicate the possibilities for redefine the transport problem.

User oriented object modeling and programming in Excel spreadsheet interface can stimulate and affirm education and training of users (business oriented human resources – managers and workers) in choosing the best computing tools and programs for designing and optimizing the transport network and also education and training of professional informatics for translating mathematical models into computer algorithms and creating their own models and programs in the transport network optimization .

The paper is composed of seven parts.

In the first part of this paper **Introduction**, the features of this work are presented.

In the second part **Urban Agglomeration Rijeka**, the meaning of agglomeration is discussed and systematized commodity-transport centers as nodes in the agglomeration transport network.

In the third part **Traveling Salesman Problem and Exhaustive Search Algorithm,** there are considered theoratical background and determinants of Traveling Salesman Problem

In the fourth part **Exhaustive search algorithm and square pyramid model of transport network in generating multiple optimal and suboptimal solutions,** there are considered the usage and meaning of Exhaustive search algorithm in the calculating and visualisation of optimal and suboptimal solutions on the example of transport network in the form of two iinterconnected square pyramids.

In the fifth part **Transport Network Optimization of the Urban Agglomeration Rijeka**, Exhaustive Search Algorithm is considered in the Transport Network Optimization in the Excel spreadsheet interface and the optimal and suboptimal solutions are presented.

In the sixth part, **The imporetance of the suboptimal solution of the transport problem on the example of Urban Agglomeration Rijeka,** there are comparatively analyzed the similarities, differences, advantages and disadvantages of the optimal and suboptimal solution.

In the seventh part **Conclusion**, the synthesis of the whole work was presented and the most important results of the research were presented.

2. Rijeka Urban Agglomeration and transport network

The Development Strategy of the Urban Agglomeration Rijeka is based on strategic and territorial documents of all cities and communes included in the Urban Agglomeration Rijeka and is linked with all strategic higher order documents. Urban Agglomeration Rijeka Development Strategy was set up by a decision adopted on 21 September 2015 by the Ministry of Regional Development and EU Funds of the Republic of Croatia and it is formed of the following towns and cities, and municipalities: 1) City of Rijeka, 2) Town of Kastav, 3) Town of Kraljevica, 4) Town of Opatija, 5) Municipality of Čavle, 6) Municipality of Klana, 7) Municipality of Kostrena, 8) Municipality of Lovran, 9) Municipality of Mošćenička Draga and 10) Municipality of Viškovo.

Towards the end of 2014, the Government of the Republic of Croatia signed the Partnership Agreement which determines the towns and cities that may benefit from the ITI (Integrated Territorial Investment) mechanism. It relates to towns and cities having more than 100,000 inhabitants, which can form urban agglomerations as well as towns and cities with more than 50,000 inhabitants that can form urban areas. The ITI mechanism is a mechanism of the European Union for the period from 2014 to 2020 introduced with the aim of strengthening the roles of towns and cities as the promoters of economic development. The mechanism serves for implementing the activities of sustainable urban development that have an emphasized territorial dimension and for providing financial support for implementing integrated activities [4].

The activities related to the implementation of integrated territorial investments may be financed from three different European funds – the European Regional Development Fund, the Cohesion Fund and the European Social Fund, as well as within the Operational programme for Croatia for 2014-2020 entitled Competitiveness and Cohesion and the Operational programme for Croatia for 2014-2020 entitled Efficient Human Resources. The total funds that have been provided for the implementation of activities dedicated to sustainable urban development in major urban centers in the Republic of Croatia is EUR 345.35 million. The

Rijeka Urban Agglomeration project has been approved and will receive funding through the use of ITI instruments [4].

Following a public debate on the implementation of new legislation, during the period from 2013 to 2014, the City of Rijeka had made the necessary preparations for the announced changes to the regional development management system. In 2013, the City of Rijeka adopted the Development Strategy of the City of Rijeka 2014-2020 (hereinafter referred to as the Strategy), in line with the Europe 2020 Strategy, as the basic platform for the development of the Urban Development Strategy, where three strategic objectives are defined [13]:

- Strategic Objective 1: Global positioning of Rijeka with the development of the Rijeka Traffic Direction.
- Strategic Objective 2: Building a competitive economy on the foundations of a knowledge society and new technologies.
- Strategic Objective 3: Ensuring dignity for all the citizens by strengthening social inclusion and developing projects of common interest.

Global positioning of Rijeka with the development of the Rijeka Traffic Direction as the Strategic Objective 1 directly contributes to the strengthening of Rijeka's competitiveness on a global level, with its port as the greatest comparative advantage. The development of the Port of Rijeka involves a whole range of supporting services with a trend of enhancing the port logistics chains. This implies linking and aligning all entities within the transport sector. The purpose of such linking is to develop the Rijeka Traffic Direction as the unique economic offer on the global market [13].

Building a competitive economy on the foundations of a knowledge society and new technologies as the Strategic Goal 2 directly contributes to the development and application of new knowledge, with emphasis on the creation of a new economic structure in the Rijeka economy. Raising the competitiveness of the Rijeka economy through new knowledge and technology means contributing to the competitiveness of the Croatian economy, which is the EU's main objective.

By combining strategic objectives 1 and 2, a common interest of all local units that form part of Rijeka Urban Agglomeration is defined, where the synergy between these two strategic objectives directly contributes to certain aspects of competitiveness with a strong influence on the economy. A transportation network allows supplying of logistics centres of towns and cities, and municipalities, their subsystems and all logistics entities in Rijeka Urban Agglomeration. A key factor in designing an efficient transportation network to create an efficient system for goods distribution is the use of relevant IT technologies and computer applications to determine optimal routing between the nodes (towns, cities, municipalities, distribution centres, ports, terminals) as well as route planning.

Rijeka Urban Agglomeration is formed of 10 towns and cities, and municipalities that represent 10 distribution and transport centers (nodes) in the transportation network. In the advanced search algorithm used in this work, the maximum number of nodes is 9. Since the town of Lovran in situated along the Opatija - Mošćenička draga route, the transportation network could be reduced, for the purpose of finding a solution, to 9 nodes. The towns and cities, and municipalities shown in the table are nodes that represent distribution and transport centers, with the node numbers from 1 to 9, where 9A denotes the Lovran node whose routes are predetermined, and which is not included in the calculation.

Table 1 shows distances between towns and cities, and municipalities of Rijeka Urban Agglomeration, which had been determined by using Google Maps technology, a web mapping service developed by Google. It offers satellite imagery, route planning, searching and finding places, etc. Google Maps automatically displays a graphic representation of the selected route.

Table 1: Distances between towns and cities, and municipalities of Rijeka Urban Agglomeration

			1	2	3	4	5	6	7	8	9
No	**City**	**Acc**	**RI**	**KR**	**KO**	**OP**	**VI**	**KA**	**ČA**	**KL**	**MO**
1	Rijeka	**RI**	0	22	9	14	9	10	9	18	28
2	Kraljevica	**KR**	22	0	14	37	31	32	17	40	57
3	Kostrena	**KO**	9	14	0	22	23	24	12	32	43
4	Opatija	**OP**	14	37	22	0	12	7	22	20	14
5	Viškovo	**VI**	9	31	23	12	0	5	16	10	26
6	Kastav	**KA**	11	32	24	7	5	0	18	13	22
7	Čavle	**ČA**	9	17	12	22	16	18	0	22	37
8	Klana	**KL**	18	40	32	20	10	13	22	0	36
9	Mošćenićka Draga	**MO**	28	57	43	14	26	22	37	36	0

3. Traveling Salesman Problem and Exhaustive Search Algorithm

The Travelling Salesman Problem (TSP) is an optimization problem used to find the shortest path to travel through the given number of cities. Travelling salesman problem states that given a number of cities N and the distance between the cities, the traveler has to travel through all the given cities exactly once and return to the same city from where he started and also the length of the path is minimized [7]. .

The Travelling Salesman Problem (TSP) is one of the most studied problems in management science. Optimal approaches to solving Travelling Salesman Problems are based on mathematical programming. But in reality, most TSP problems are not solved optimally. When the problem is so large that an optimal solution is impossible to obtain, or when approximate solutions are good enough, heuristics are applied. Two commonly used heuristics for the Travelling Salesman Problem are the nearest neighbour procedure and the Clark and Wright savings heuristic [2].

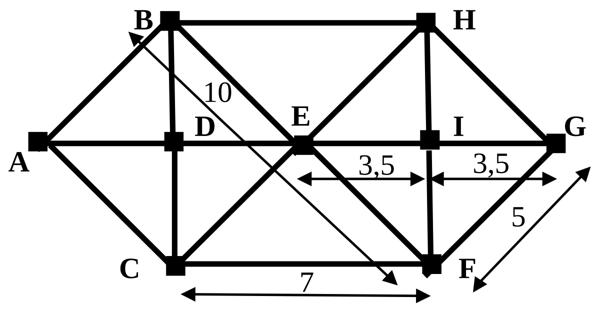
In terms of combinatorial optimization, the Travelling Salesman Problem (TSP) can be formulated in the following way: Given a list of *n* cities C and distance dij from city *i* to city *j*; TSP, is to find the best possible way of visiting all the cities by visiting each city only once finding minimum total travel distance. In analogy to the above definition, the following formulations are valid: 1) Travel distance or distance between cities is symmetric: $d_{ij} = d_{ji}$ (1) or asymmetric d_{ij} # d_{ji} (2); 2) Final list of cities is defined as incoming variable by the formula C = (c_1 … c_n), while distance matrix containing distance between city c_i and city c_j for each pair i,j is defined by $d(c_i,c_j)$; 3) Permutations or in other words all permuted relations that can be achieved for a given number of cities are computed as resulting variables. Permutations p(1), …, p(n) in the list 1, …, n are calculated and compared to give the minimum sum [1], [10].

Exhaustive search algorithm, also known as brute force seach, is a very general problem-solving technique. In the Travelling Salesman Problem (TSP), every tour corresponds to a permutation of the cities. In a permutation problem every freasible solution can be specified as a total ordering of an underlying ground set [3]. The Exhaustive Search Algorithm enumerating all possible candidates for the solution (permutations) and checking whether each candidate satisfies the problem's statement. It is considered as approach to apply and is useful for solving small–size instances of a problem.

4. Exhaustive search algorithm and square pyramid model of transport network in generating multiple optimal and suboptimal solutions

Choosing the relevant information technology and computer software to enable us to create optimal node connections (cities, distribution centres, ports, and terminals), and arrange the optimal transportation routes, is the key factor of the transportation network modeling and optimization. Object-oriented programming in spreadsheet interface allows us to design and visualize Exhaustive search algorithm to solve the Travelling Salesman Problem, and identify multiple optimal and suboptimal solutions in the transport network optimization.

Figure 1. Transport network in the form of two interconnected square pyramids



Model of transportation network that uses a base of a square pyramid allow us to demonstrate and analyze possibilities of generating a large number of optimal solutions that have equal or similar values. The base of a square pyramid [12] is a square having equal sides and equal angles. The base of a square pyramid is also made of diagonals that intersect at right-angles. The intersection of diagonals is the central node of the base that is equally distant from all other nodes.

Figure 1 shows a system of two interconnected square pyramids that represent the transport network. Nodes of transport networks representing cities and municipalities are marked by squares, and transport routes are marked by lines. Table 3 shows the input data and the solution in the Excel spreadsheet interface.

The cell range K1:S9 in the Table 3 contains transportation route lengths (lines) that correspond to the dimensions indicated in the square pyramid model in the Figure 1. The cell range J1:J40320 offers all possible solutions, which have been categorized from the lowest to the highest.

Table 3 shows that 36 optimal solutions were calculated resulting in equal minimum values of the total transport relation (J1:J36) and the corresponding structures of optimal transport routes (A1:I36). Considering the matrix from the cell range K1:S9 is symmetric, it follows that the model has generated 18 optimal solutions. Figure 2 is a graphical representation end example of two optimal solutions calculated in Row 1 and Row 3 in Table 3

Table 3. The input data and the solution in the Excel spreadsheet interface

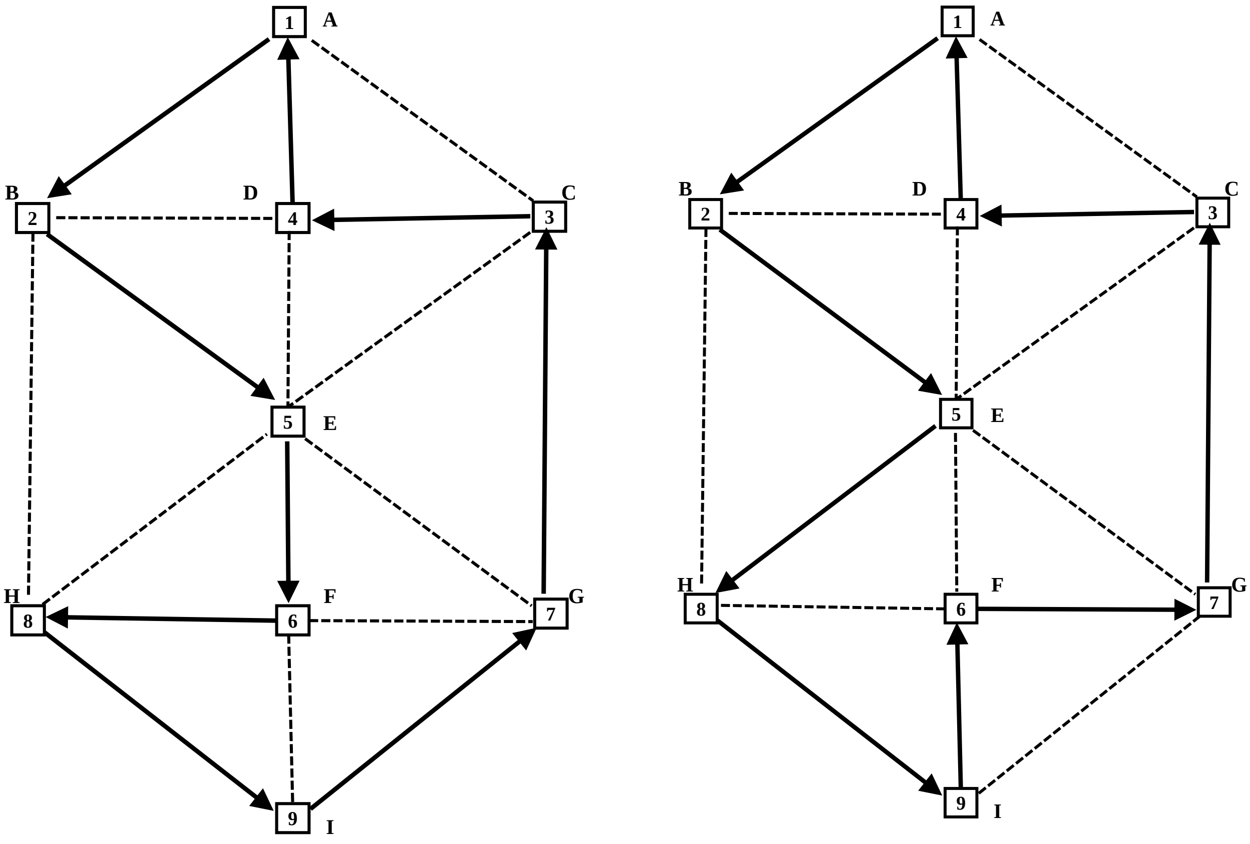
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	**1**	**2**	**5**	**6**	**8**	**9**	**7**	**3**	**4**	**41**	1,0	5,0	5,0	3,5	7,0	10,5	11,0	11,0	14,0	**1**	**A**
2	**1**	**2**	**5**	**8**	**6**	**9**	**7**	**3**	**4**	**41**	5,0	1,0	7,0	3,5	5,0	8,0	10,0	7,0	11,0	**2**	**B**
3	**1**	**2**	**5**	**8**	**9**	**6**	**7**	**3**	**4**	**41**	5,0	7,0	1,0	3,5	5,0	8,0	7,0	10,0	11,0	**3**	**C**
4	**1**	**2**	**8**	**9**	**7**	**6**	**5**	**3**	**4**	**41**	3,5	3,5	3,5	1,0	3,5	7,0	8,0	8,0	10,5	**4**	**D**
5	**1**	**2**	**8**	**9**	**6**	**7**	**5**	**3**	**4**	**41**	7,0	5,0	5,0	3,5	1,0	3,5	5,0	5,0	7,0	**5**	**E**
6	**1**	**2**	**8**	**6**	**9**	**7**	**5**	**3**	**4**	**41**	10,5	8,0	8,0	7,0	3,5	1,0	3,5	3,5	3,5	**6**	**F**
7	**1**	**2**	**8**	**6**	**9**	**7**	**5**	**4**	**3**	**41**	11,0	10,0	7,0	8,0	5,0	3,5	1,0	7,0	5,0	**7**	**G**
8	**1**	**2**	**8**	**9**	**6**	**7**	**5**	**4**	**3**	**41**	11,0	7,0	10,0	8,0	5,0	3,5	7,0	1,0	5,0	**8**	**H**
9	**1**	**2**	**8**	**9**	**7**	**6**	**5**	**4**	**3**	**41**	14,0	11,0	11,0	10,5	7,0	3,5	5,0	5,0	1,0	**9**	**I**
10	**1**	**2**	**4**	**5**	**6**	**8**	**9**	**7**	**3**	**41**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
11	**1**	**2**	**4**	**5**	**8**	**9**	**6**	**7**	**3**	**41**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**		
35	**1**	**3**	**5**	**7**	**9**	**6**	**8**	**2**	**4**	**41**											
36	**1**	**3**	**5**	**6**	**7**	**9**	**8**	**2**	**4**	**41**											
37	**1**	**2**	**8**	**6**	**9**	**7**	**3**	**5**	**4**	**43**											
38	**1**	**2**	**8**	**9**	**6**	**7**	**3**	**5**	**4**	**43**											
40319	**1**	**9**	**4**	**8**	**3**	**5**	**7**	**2**	**6**	**81**											
40320	**1**	**6**	**3**	**8**	**5**	**2**	**7**	**4**	**9**	**81**											

Source: Authors

Figure 2. Graphical display of optimal solutions calculated in Table 3

Optimal solution calculated in Row 1
1 – 2 – 5 – 6 – 8 – 9 – 7 – 3 – 4 – 1

Optimal solution calculated in Row 3
1 – 2 – 5 – 8 – 9 – 6 – 7 – 3 – 4 - 1



Source: Authors

5. Transport network optimization of Urban Agglomeration Rijeka

In the transport network optimization of Urban Agglomeration Rijeka, Exhaustive Search Algorithm built in Visual Basic has been used. Object-oriented programming in Visual Basic has been used to build and visualize Exhaustive Search Algorithm to calculate one or multiple optimal transportation routes. Table 4 contains travelling salesman problem (TSP) results.

Table 4. Solution of transport network in program Visual Basic for Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	1	9	4	6	5	8	7	2	3	126	0	22	9	14	9	10	9	18	28	1	RI	Rijeka
2	1	3	2	7	8	5	6	4	9	126	23	0	14	37	31	32	17	40	54	2	KR	Kraljevica
3	1	4	9	6	5	8	7	2	3	127	9	14	0	22	23	24	12	32	49	3	KO	Kostrena
4	1	3	2	7	8	5	6	9	4	127	14	37	22	0	12	7	22	20	14	4	OP	Opatija
5	1	9	4	6	8	5	7	2	3	128	9	31	23	12	0	5	16	10	26	5	VI	Viškovo
6	1	3	2	7	5	8	6	4	9	128	11	32	24	7	5	0	18	13	22	6	KA	Kastav
7	1	4	9	6	8	5	7	2	3	129	9	17	12	22	16	18	0	22	37	7	ČA	Čavle
8	1	6	4	9	5	8	7	2	3	129	18	40	32	20	10	13	22	0	36	8	KL	Klana
9	1	3	2	7	5	8	6	9	4	129	28	58	50	14	26	22	37	36	0	9	MO	Mošćenička Draga
10	1	7	2	3	4	9	6	8	5	130	1	2	3	4	5	6	7	8	9			
11	1	6	9	4	5	8	7	2	3	130	RI	KR	KO	OP	VI	KA	ČA	KL	MO			
12	1	5	8	6	9	4	7	2	3	130												
13	1	5	8	6	4	9	7	2	3	130		**Provjera rezultata**										
14	1	5	8	6	9	4	3	2	7	130												
15	1	3	2	7	8	5	9	4	6	130		**Ri - Mo - Op - Ka - Vi - Kl - Ča - Kr - Ko - Ri**										
16	1	3	2	7	4	9	6	8	5	130		1	9	4	6	5	8	7	2	3	1	
17	1	3	2	7	9	4	6	8	5	130		=28 + 14 + 7 + 5 + 10 +22 +17 +14 + 9										
18	1	7	2	3	4	9	6	5	8	131		**126**										
19	1	8	5	6	4	9	7	2	3	131												
20	1	8	5	6	9	4	7	2	3	131												
40319	1	8	3	9	2	5	4	7	6	251												
40320	1	8	3	9	2	4	5	7	6	251												

Source: Authors

Table 5. Optimal and suboptimal transport routes within acceptable tolerance

No	Optimal and suboptimal transport routes										Length	Tol.
1	1	9	4	6	5	8	7	2	3	1	126	0,0%
	RI	MO	OP	KA	VI	KL	ČA	KR	KO	RI		
1	1	3	2	7	8	5	6	4	9	1	126	0,0%
	RI	KO	KR	ČA	KL	VI	KA	OP	MO	RI		
2	1	4	9	6	5	8	7	2	3	1	127	0,8%
	RI	OP	MO	KA	VI	KL	ČA	KR	KO	RI		
2	1	3	2	7	8	5	6	9	4	1	127	0,8%
	RI	KO	KR	ČA	KL	VI	KA	MO	OP	RI		
3	1	9	4	6	8	5	7	2	3	1	128	1,6%
	RI	MO	OP	KA	KL	VI	ČA	KR	KO	RI		
3	1	3	2	7	5	8	6	4	9	1	128	1,6%
	RI	KO	KR	ČA	KL	VI	KA	OP	MO	RI		
4	1	4	9	6	8	5	7	2	3	1	129	2,4%
	RI	OP	MO	KA	KL	VI	ČA	KR	KO	RI		
4	1	6	4	9	5	8	7	2	3	1	129	2,4%
	RI	KA	OP	MO	VI	KL	ČA	KR	KO	RI		
5	1	3	2	7	5	8	6	9	4	1	129	2,4%
	RI	KO	KR	ČA	VI	KL	KA	MO	OP	RI		
6	1	7	2	3	4	9	6	8	5	1	130	3,2%
	RI	ČA	KR	KO	OP	MO	KA	KL	VI	RI		

Source: Authors

In the transport network optimization, Exhaustive Search Algorithm built in Visual Basic has been used. Object-oriented programming in VBA for Excel has been used to build and visualize Exhaustive search algorithm in order to compute one or multiple optimal transportation routes. It can be seen from the Table 4, that 40,320 possible transport routes (permutations) have been computed with the minimum route length having 126 km. The results have been calculated by program Visual Basic in Excel spreadsheet interface (VBA for Excel), created by the authors of this work.

Table 5 reveals optimal transportation routes having values within an acceptable tolerance of 3% as compared to the best optimal value, or minimum route length as calculated. In Table 5 in the column No the same ordinal numbers indicate the relations that are symmetrical. From the table it is seen that the relation No 1 is optimal, and relations from No 2 to No 6 are suboptimal relations.

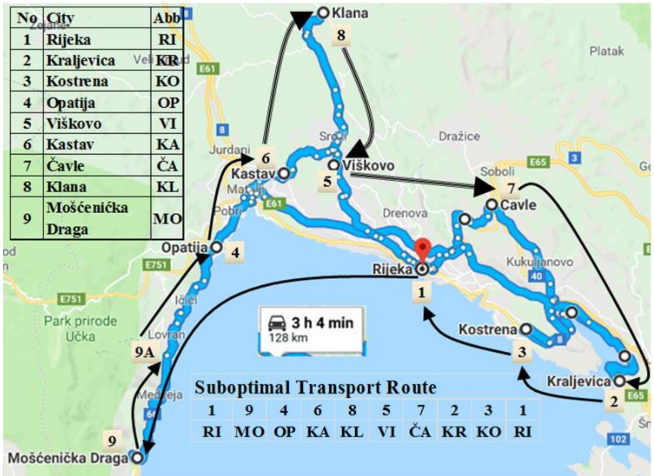
In the described example of the transport network optimization of Urban agglomeration Rijeka, the criterion (factor) of optimization is the minimum length of the transport relation. Considering the more optimal solutions within a given deviation interval, it is possible to parse and analyze the synergy of all relevant factors that determine the best (optimal) or set of best solutions.

Map 1 is the graphical display of the optimal transportation route (No1 in Table 5) having the minimal length. The map shows ordinal numbers of cities and optimal transport route, names of cities and their ordinal numbers and abbreviations are indicated in the left part of the figure, while the optimal transport route is shown in down part of the figure.

Map 2 is the graphical display of the suboptimal transportation route No. 3 in Table 4 of Urban agglomeration Rijeka. The suboptimal solution to Map 2 corresponds to the solution under No. 3 shown in Table 5. By comparing the optimum solution to map 1 and the suboptimal solution to the map 2. where is a difference in the transport relation segment Kastav (6) – Viškovo (5) – Klana (8) – Čavle (7) can be seen the change of order of nodes in the tranport network. On the map, the 2-bold arrows indicate the segment of the transport network that has been changed. The changed order of nodes of the suboptimal transport network solution is Kastav (6) - Viškovo (5) - Klana (8) - Viškovo (5) - Čavle (7).

Map 1 Optimal transport route

Map 2. Suboptimal transportation route of Urban Agglomeration rijeka



6. Significance of suboptimal solutions of the transportation problem illustrated by the example of Urban Agglomeration Rijeka

In the described example of the transport network optimization of Urban agglomeration Rijeka, the criterion (factor) of optimization is the minimum length of the transport relation. Considering the more optimal solutions within a given deviation interval, it is possible to parse and analyze the synergy of all relevant factors that determine the best (optimal) or set of best solutions (transport cost and time, choosing the alternative route in case of traffic jams, the greater utilization of transport capacity [8].The Traveling Salesman Problem (TSP) is a problem which requires an optimal solution, especially if the route is to be used several times. In general, if the solution is to be applied only once, a suboptimal solution will be adequate and a very close to optimal solution may be even more desirable than the optimal solution [5].

Sequential insertion with possible requests for variable quotes to all trucks and to all routes potentially produces suboptimal solutions [6]. Significance of suboptimal solutions to the transportation problem of Rijeka Urban Agglomeration is illustrated by a hypothetical example as shown in Table 6.

Table 6. Comparison of two transportation routes and suboptimal solution on the example of Urban agglomeration Rijeka

	Route1		Route 2
	Destination1	Origin	Destination2
	Viškovo←	Kastav→	Klana
TTC	1000	1000	1000
RTC	700	500	900
FTC	**300**	**500**	**100**
LCU	**70%**		**90%**
Input1	200		200
Input2	0		200
Input	**200**		**400**

Source: Authors

The example shows the following parameters: Total Transport Capacity (TTC), Reserved Transport Capacity (RTC), Free Transport Capacity (FTC), Loading Cargo Units (Inputs), Fixed Quote of Loading

(Input1), Variable Quote of Loading (Input2) and Load Capacity Utilization (LCU).

The following formulas are used:

Input = Input1 + Input2

RTC = RTC + Input

FTC = TTC – RTC

LCU = RTC/TTC*100

With the following limit:

FTC > 0

The table shows a comparison of the two transportation routes: Route 1 (Kastav - Viškovo) and Route 2 (Kastav - Klana). Map 1 reveals that Route 1 is the optimal solution of the total transportation route of Rijeka Urban Agglomeration, while Map 2 suggests that Route 2 is a suboptimal solution.

In the example, as shown in Table 6, Load Capacity Utilization (LCU) is analyzed. The origin is Kastav, and potential destinations are Viškovo (Route 1) and Klana (Route 2). The data in the origin column (Kastav) are values for TTC, RTC, and FTC, whereas the data in the destination columns (1 and 2) are values of the fixed and variable quotes of loadings, transported along Route 1 and Route 2. The table reveals that the fixed quotes of loadings (Input1) that are loaded at the origin (Klana) are equal for both routes. The variable quotes are different, with the quote for Route 1 (Kastav - Viškovo) being equal to 0, and the quote for Route 2 (Kastav - Klana) is 200. Choosing Route 2 increases the load capacity utilization. The table shows that the value of LTC on Route 1 equals 70%, and LTC on Route 2 is equal to 90%.

7. Conclusions

In the optimization of the transportation network of Urban agglomeration Rijeka, the Exhaustive search algorithm was developed and written in the Visual Basic programming language. Object Modeling and Programming in the Spreadsheet Interface (VBA for Excel) is considered in the design and visualization of a detailed search algorithm for calculating one or more optimal transport relationships. The scientific contribution of this paper is reflected in the fact that most of today's software solutions enable calculation and insight into one optimum solution and consideration of the significance of using suboptimal solutions to the transport problem on the example of Urban agglomeration Rijeka. In the paper, it has been proven that visual and objective programming and modeling methods in designing the exhaustive search algorithm can generate models with more suboptimal solutions for smaller samples (up to 10 merchandise transport centers) with clear interpretation of results not only for the same optimum values but also about the same values and with the definition of allowed deviations from the optimal values.

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