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ACCESSIBILITY MODEL FOR THE EVALUATION OF TRANSPORT INFRASTURCTURE POLICY

Maciej Mączka
Institute of Aviation, Al. Krakowska 110/114, 02-256 Warsaw
maciej.maczka@ilot.edu.pl

Abstract

The paper presents a simple, deterministic tool for an evaluation of transportation infrastructure policy. It requires the input of a complete graph representing examined transport network. The proposed method uses European Commission daily accessibility indicator and the Floyd-Warshall shortest path algorithm. The accessibility indicator distinguishes groups of travellers in terms of those who have an opportunity to complete a one-day journey of any purpose and those who do not. Setting adequate public policy objectives, such as for example increasing share of population able to complete one-day journey, is more transparent and easier to evaluate when using this method. It is possible to expand the tool and increase precision (number and types of nodes), include rules of quality decrease on links (capacity), add new modes of travel, calculate travel costs or externalities (emissions, noise). Limits of the model expansion are: data sources availability and computational power.
Keywords: accessibility, transport policy, spatial modelling, graph theory.

1. INTRODUCTION

The total daily accessibility is one of the criteria of assessment of the Sustainable Transportation Strategies [1] and it enables to examine the achievement of the European Commission regional cohesion goal described as **"90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours."** [2], [3], [4]

Full scale transportation engineering analyses require multiple inputs of data and a huge computational power. Such a project (or projects) could involve, equally important, planning, evaluations, simulations, estimations, and concrete designs [1] [5]:

- planning of network, urban transportation, railroad, trucking, aircraft, maritime operations, parking management, pedestrians and bicyclists facilitation, vehicles and infrastructure maintenance, risk management;
- evaluating micro levels and system level reliability and robustness;
- estimating travel demand, origin-destination flows, capacity, congestion, and safety;
- designing complete details of railway vehicles, Automated Guideway Transit systems, tracks, roads, controls, signals, signs, lighting, rigid and flexible pavements, bridges, tunnels, aircraft, airport, air traffic control, maritime vessels, and pipelines;
- considering noise and air quality or fragmented landscape issues effects.

A fraction of transport research presented here could be located in the domain of total network planning and evaluation. Total network adequateness, its structure and quality determine levels of accessibility inherent for public policy objectives in transport: "[…] the network design problem can be seen as a Stackelberg game in which one decision maker, i.e., the network designer, has full knowledge of the decisions of the second decision maker, the traveller, and uses this information to achieve […] objectives." [1]

Cost-benefits and effects of a set of improvements could be numerically tested with respect to:

- maximising accessibility (knowing network origin-destination distances or travel time);
- minimising costs (knowing unit travel costs by mode and value of time in travel);
- optimising costs (knowing the above and improvement unit costs);
- minimising externalities (knowing burdens, such as e.g. unit emission volumes among modes);
- matching network capacity to an expected demand (knowing historical/expected flow volumes by mode).

2. METHOD DESCRIPTION

The proposed method utilizes the Floyd-Warshall shortest paths algorithm [6] and, derived from the algorithm outcome, a total daily accessibility indicator. The indicator is then used to evaluate effects of infrastructure quality improvements. A random network structure given in the example can be easily (but not effortlessly) transposed into a model reflecting a real-world system (e.g. the one similar to European TENTEC or the one of the EU Member State infrastructure).

2.1. Literature review

Territorial development and cohesion in the European Union is analysed by European Spatial Planning and Observation Network (ESPON) [7]. The Institute of Geography and Spatial Organization of the Polish Academy of Sciences (IGiPZ PAN) contributed to ESPON efforts and specialises in transport accessibility with respect of Poland. The IGiPZ team refined and published [8] an extensive review of literature in the subject of transport accessibility analysis methods [9] [10] [11] [12] [13] [14] that had emerged until 2009. The list includes the following, substantially different accessibility measures:

- infrastructure-based – analysing capacity, travel time - used in transport planning,
- isochrones-based (location-based) – analysing locations on macro level, for example population within 30 minutes of travel – used in urban planning and geographic studies,
- potential-based – measuring possibility of interaction between source of travel and a set of destinations (gravity models),
- space-time geography-based (the Hägerstrand accessibility measure) – a feasibility of opportunities to an individual on daily paths (grouped in "bundles"),
- utility-based – stochastically analysing individual behaviour– used in economic studies.

Since 2009, researchers have worked on enriching the knowledge on accessibility measures with the incorporation of network effects [15] or setting relationship among infrastructure, accessibility and economic growth [16], and relationship between accessibility and safety [17]. Moreover, the improvements of methods included: stochastic approach to accessibility in freight transport [18], social responsibility for vulnerable groups (e.g. seniors) [19], using GIS techniques on population density in mesh blocks [20]. One of the most acute challenges is the need to understand better how "all kinds of accessibility effects should be included in wider evaluation frameworks" [21].

2.2. Definition of accessibility

According to ESPON, accessibility "expresses how easy people in one region can reach people in another region." [22] Whereas a daily accessibility is an isochrones-based measure "[…] derived from the example of a business traveller who wishes to travel to a certain place in order to conduct business there and who wants to be back home in the evening." [23]

The abovementioned EC regional cohesion goal (**"90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours."** [2] [3]) is a percentage share of total population with daily accessibility level of four hours, maximum. Four hours of travel limit in one direction comes from the assumed average day that includes 8 hours of work, 8 hours of non-work and 8 hours of rest which nearly corresponds to a typical daily work activity in European Union Member States [24]. See figure 1.

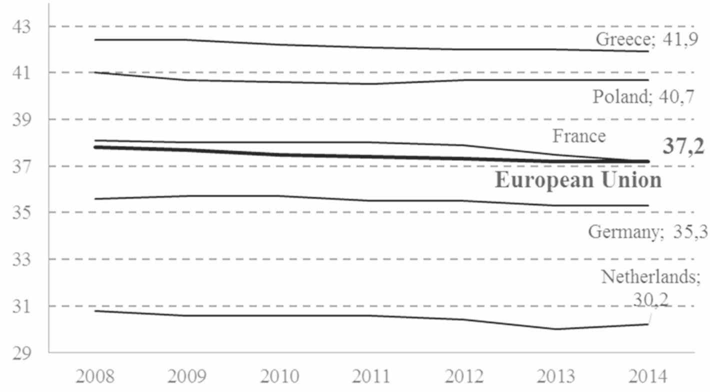


Fig. 1. Weekly working conditions in the EU (in hours) [EUROSTAT] [Mączka, 2016]

2.3. Deriving daily accessibility indicators form the shortest path algorithm

The daily accessibility was calculated as a real number between 0 and 1 expressing share of total population that could be reached in less than 4 hours of travel.

To reflect an actual pattern of routes among regions, a deterministic view of travel utility [25] was used. For this purpose, an equilibrium of transport network where "no user can improve his travel time by unilaterally changing routes" [26] (also called Wardrop's first principle [27]) was assumed. It meant all transport was driven along the shortest paths – there were no deviations such as random sightseeing or suboptimal paths choice habits. System capacity or costs, however, were not considered. Technically, the transport system was expressed as a weighted mathematical graph G with no negative cycles:

$$G = (V, E) \quad (1)$$

A degree details depends on the analysis purpose and it could be adjusted to the perspective a decision maker (traveller, pilot, driver, operations planner, policy planner, etc.). Since the method's purpose was policy evaluation, the policy planner perspective was taken which entailed a compromise of lowering degree of graph details to see the bigger picture within the computational capabilities. And thus, the graph G consisted of k vertices (nodes) and m edges that connected the adjacent vertices (node-to-node links), where: $v \in V$ and $e \in E$.

The vertices of graph represented centroids of mutually exclusive zones. The centroids had certain properties (e.g. population) and generalised origins, destinations or junctions of paths of travels. The paths of travels $p = \{v_1, v_2, \dots, v_{number\ of\ paths}\}$ were aligned to the graph's weighted edges. The weight of edges expressing quality of linking between vertex i and vertex j were defined as the following:

$$w_{ij} = \begin{cases} 0 & if\ i = j \\ the\ weight\ of\ an\ edge\ (i,j) & if\ i \neq j\ and\ (i,j) \epsilon E \\ \infty & if\ i \neq j\ and\ (i,j) \notin E \end{cases} \quad (2)$$

The weights equalled to time of travel and consisted of two elements – one that was constant (distance) and one that was possible to be improved (maximum speed):

$$the\ weight\ of\ an\ edge\ (i,j) = \frac{distance}{max.speed} \quad (3)$$

Having established the graph structure, the Floyd-Warshall algorithm [6] was applied to obtain the shortest paths. The algorithm was calculated in an iterative way and its two formulae were the following:

$$d_{ij}^{(k)} = \begin{cases} w_{ij} & if\ k = 0 \\ \min\left(d_{ij}^{(k-1)}, d_{ik}^{(k-1)} + d_{kj}^{(k-1)}\right) & if\ k \geq 1 \end{cases} \quad (4)$$

$$\pi_{ij}^{(k)} = \begin{cases} \pi_{ij}^{(k-1)} & if\ d_{ij}^{(k-1)} \leq d_{ik}^{(k-1)} + d_{kj}^{(k-1)} \\ k & if\ d_{ij}^{(k-1)} > d_{ik}^{(k-1)} + d_{kj}^{(k-1)} \end{cases} \quad (5)$$

where: d – a time matrix value, π – a sequence matrix value, i – node of origin, j – node of destination, k – a sequence counter

After the final iteration, all of the obtained shortest times were compared to the limit (chosen by the evaluated policy). Populations of the zones for which the 4-hour daily accessibility condition held true were summed up:

$$accessibile\ population_i = \sum_1^j population_j \qquad if\ d_{ij}^{(k)} < 4 \quad (6)$$

The final result for a single zone was a daily accessibility level:

$$A_i = \frac{accessibile\ population_i}{total\ population} \quad (7)$$

To complete the country-wide picture, the total daily accessibility was calculated by aggregating fractions of populations of all zones that met the assumed policy goal (e.g. 0.90 as in the case of the EU cohesion goal):

$$total\ daily\ accessibility = \sum_1^j population_j \qquad if\ A_i > 0.90 \quad (8)$$

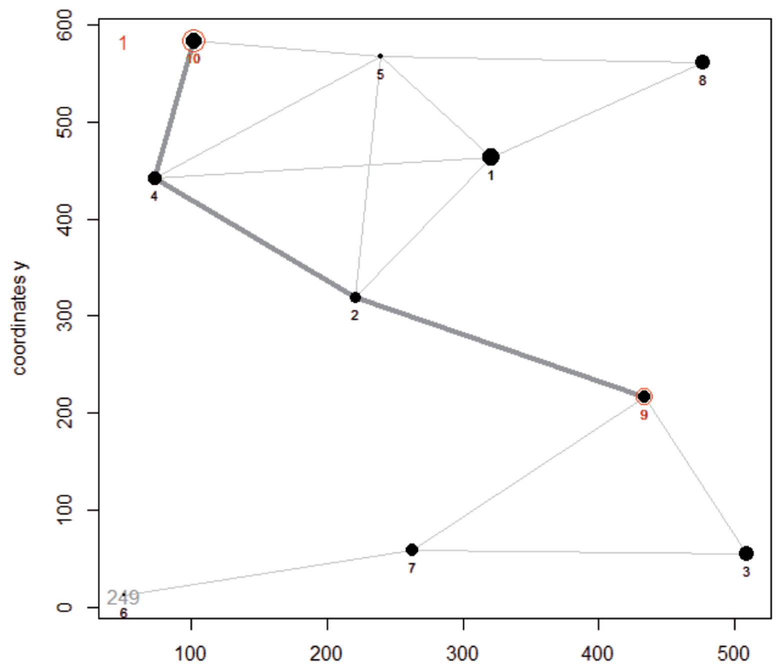
The method can simulate implementation of transport policy by network improvements. Change of the maximum speed from some lower (e.g. 50 km/h) to some higher (e.g. 140 km/h) on selected (or all) edges generates new daily accessibility levels and new population shares fulfilling the cohesion policy assumptions. Finally, it is possible to validate policy objectives and estimate improvements rough order of magnitude (provided infrastructure unit costs are available).

3. EXAMPLE OF AMETIP APPLICATION

In the example, a total daily accessibility estimation of a transport system with one mode of travel and two quality levels is presented. A small number of ten zones were assumed. Network generation and all calculations were programmed in the environment of R Project for Statistical Computing [28]. Precision of the analysis could be increased in further derivatives of the method provided more computational power and data.

3.1. Random network generation: vertices and edges

A certain number (i=10) of vertices were randomly located within 2-dimensional space (width x height). Then, a random sample from an interval <0;1> was drawn to determine weight of each vertex (population). All combinations of Euclidean distances were presented in the DM matrix (table 1). In further applications, instead of Euclidean distance, the great-circle distance formula is suggested, especially if distances cover thousands of kilometres.



	x	y	pop
1	321	463	0.95
2	221	319	0.61
3	509	55	0.85
4	73	442	0.78
5	239	567	0.30
6	50	12	0.09
7	263	59	0.66
8	477	561	0.82
9	434	216	0.67
10	101	583	0.89
			6.62

vertices = 10
edges = 15
width = 600; height = 600;
mode of distance = 249;

hi-quality nodes = [9; 10];
completeness of path = 1

Fig. 2. Graph visualisation representing some random transport system [Mączka, 2016]

Now, to imitate proportions of a real transportation system, only some of the vertices were linked. Figure 2 presents the resulting spatial distribution.
The adjacency generation, expressed in KD matrix (table 2), relied on the following rules:

a) a distance limit: excluding all DM values greater than an integer number of the mode of (the most frequent) DM value;

b) the closest node: including to point a) all of the minimum values of each of DM rows to corresponding locations of the KD rows (reducing vertices with no edges to close the network);
c) the both ways: symmetry in adjacency (edges are undirected).

Table 1. DM matrix (i x i) of Euclidean distances [Mączka, 2016]

	1	2	3	4	5	6	7	8	9	10
1	0	175	449	249	132	526	408	184	272	251
2	175	0	391	192	249	351	263	352	237	290
3	449	391	0	583	579	461	246	507	178	667
4	249	192	583	0	208	431	428	421	426	144
5	132	249	579	208	0	586	509	238	402	139
6	526	351	461	431	586	0	218	696	435	573
7	408	263	246	428	509	218	0	546	232	548
8	184	352	507	421	238	696	546	0	348	377
9	272	237	178	426	402	435	232	348	0	496
10	251	290	667	144	139	573	548	377	496	0

Table 2. KD matrix (i x i) of edges lengths (NA – not applicable) [Mączka, 2016]

	1	2	3	4	5	6	7	8	9	10
1		175	NA	249	132	NA	NA	184	NA	NA
2	175		NA	192	249	NA	NA	NA	237	NA
3	NA	NA		NA	NA	NA	246	NA	178	NA
4	249	192	NA		208	NA	NA	NA	NA	144
5	132	249	NA	208		NA	NA	238	NA	139
6	NA	NA	NA	NA	NA		218	NA	NA	NA
7	NA	NA	246	NA	NA	218		NA	232	NA
8	184	NA	NA	NA	238	NA	NA		NA	NA
9	NA	237	178	NA	NA	NA	232	NA		NA
10	NA	NA	NA	144	139	NA	NA	NA	NA	

KD matrix was used to create a SPEED matrix (n x n) in two steps, which reflects the adjacency quality (Table 3). Initially, all non-NA KD values were set at 50. The value of 50 was chosen to imitate quality proportions of a real transportation network (as e.g. 50 km/h of speed limit in built-up area in Poland). Then, a set of higher quality nodes was randomly drawn and its values replaced *h* out of *i* lower quality links of the SPEED matrix, overwriting values of 50 with 140 (as e.g. 140 km/h of highways speed limit in Poland). In reality, highways not necessarily overlap local roads, they can exist simultaneously.

Table 3. SPEED matrix (i x i) of lower (50) and higher (140) quality of edges [Mączka, 2016]

	1	2	3	4	5	6	7	8	9	10
1		50	NA	50	50	NA	NA	50	NA	NA
2	50		NA	140	50	NA	NA	NA	140	NA
3	NA	NA		NA	NA	NA	50	NA	50	NA
4	50	140	NA		50	NA	NA	NA	NA	140
5	50	50	NA	50		NA	NA	50	NA	50
6	NA	NA	NA	NA	NA		50	NA	NA	NA
7	NA	NA	50	NA	NA	50		NA	50	NA
8	50	NA	NA	NA	50	NA	NA		NA	NA
9	NA	140	50	NA	NA	NA	50	NA		NA
10	NA	NA	NA	140	50	NA	NA	NA	NA	

For the next step of analysis, since Floyd-Warshall algorithm requires a single matrix input, the adjacency matrix TIME (i x i) was prepared by dividing the KD distance values by the corresponding SPEED values (ignoring the diagonal zeros and NAs representing non-adjacency) – see table 4.

Table 4. The adjacency TIME matrix (i x i) of time among all nodes using all lower and higher quality links [Mączka, 2016]

	1	2	3	4	5	6	7	8	9	10
1	0	3.51	NA	4.98	2.65	NA	NA	3.68	NA	NA
2	3.51	0	NA	1.37	4.97	NA	NA	NA	1.69	NA
3	NA	NA	0	NA	NA	NA	4.92	NA	3.55	NA
4	4.98	1.37	NA	0	4.16	NA	NA	NA	NA	1.03
5	2.65	4.97	NA	4.16	0	NA	NA	4.76	NA	2.78
6	NA	NA	NA	NA	NA	0	4.36	NA	NA	NA
7	NA	NA	4.92	NA	NA	4.36	0	NA	4.64	NA
8	3.68	NA	NA	NA	4.76	NA	NA	0	NA	NA
9	NA	1.69	3.55	NA	NA	NA	4.64	NA	0	NA
10	NA	NA	NA	1.03	2.78	NA	NA	NA	NA	0

3.2. Accessibility levels of the random network

The shortest path Floyd-Warshall algorithm was conducted, and, after 10 iterations, the PATHTIME matrix (table 5) with shortest times of travel was obtained.

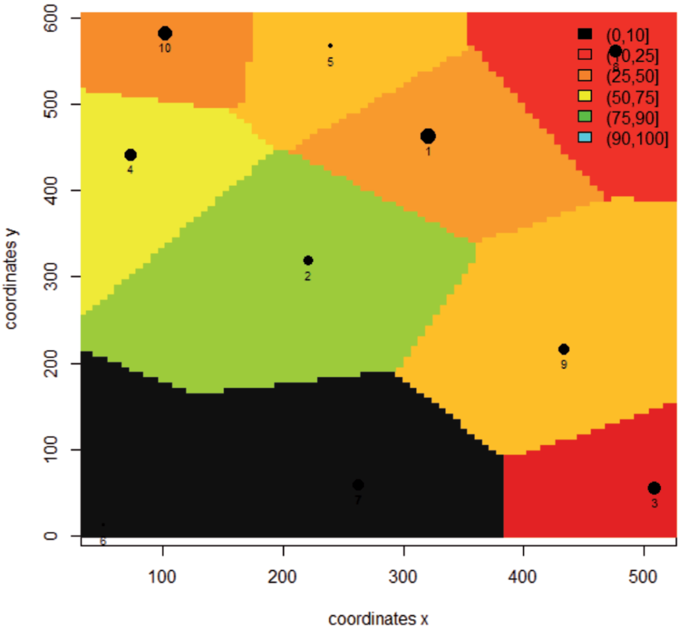
Table 5. PATHTIME matrix (i x i) of total time of each of the shortest paths [Mączka, 2016]

	1	2	3	4	5	6	7	8	9	10
1	0	3.51	8.75	4.88	2.65	14.20	9.84	3.68	5.20	5.43
2	3.51	0	5.24	1.37	4.97	10.70	6.33	7.19	1.69	2.40
3	8.75	5.24	0	6.62	10.22	9.28	4.92	12.43	3.55	7.64
4	4.88	1.37	6.62	0	3.81	12.07	7.71	8.57	3.06	1.03
5	2.65	4.97	10.22	3.81	0	15.67	11.31	4.76	6.66	2.78
6	14.20	10.70	9.28	12.07	15.67	0	4.36	17.89	9.01	13.10
7	9.84	6.33	4.92	7.71	11.31	4.36	0	13.52	4.64	8.73
8	3.68	7.19	12.43	8.57	4.76	17.89	13.52	0	8.88	7.54
9	5.20	1.69	3.55	3.06	6.66	9.01	4.64	8.88	0	4.09
10	5.43	2.40	7.64	1.03	2.78	13.10	8.73	7.54	4.09	0

To determine daily accessibility levels, a policy condition (travel time lower than 4 hours) was applied. The procedure was presented on an example for Node 1 (table 6) for which, the daily accessibility was 2.68/6.62 = 0.40. The results for all nodes are presented in figure 3.

Table 6. Example of daily accessibility calculation for Node 1 [Mączka, 2016]

nodes	Total time from Node 1	Policy condition (<4,00)	Population of nodes	accessible population
1	0	TRUE	0.95	0.95
2	3.51	TRUE	0.61	0.61
3	8.75		0.85	
4	4.88		0.78	
5	2.65	TRUE	0.30	0.30
6	14.20		0.09	
7	9.84		0.66	
8	3.68	TRUE	0.82	0.82
9	5.20		0.67	
10	5.43		0.89	
			Σ 6.62	Σ 2.68



	pop	sum	A_i level
1	0.95	2.68	0.40
2	0.61	3.90	0.59
3	0.85	1.52	0.23
4	0.78	3.25	0.49
5	0.30	2.92	0.44
6	0.09	0.09	0.01
7	0.66	0.66	0.10
8	0.82	1.77	0.27
9	0.67	2.91	0.44
10	0.89	2.58	0.39
Σ	6.62		

Fig. 3. Initial accessibility levels. Intensity of colours represent share of the total population accessible in 4h (A_i) [Mączka, 2016]

The total daily accessibility was $\frac{0+0+0+0+0+0+0+0+0+0}{6.62} = 0$. None of the zones achieved the policy target of 0.90.

3.3. Improvement testing

A visualisation of daily accessibility levels per zone in a decreasing order gives a clear image of initial situation to a decision maker. A decision maker can roughly estimate validity and scale of intervention of any transport policy goal by choosing a point on the graph (See figure 4).

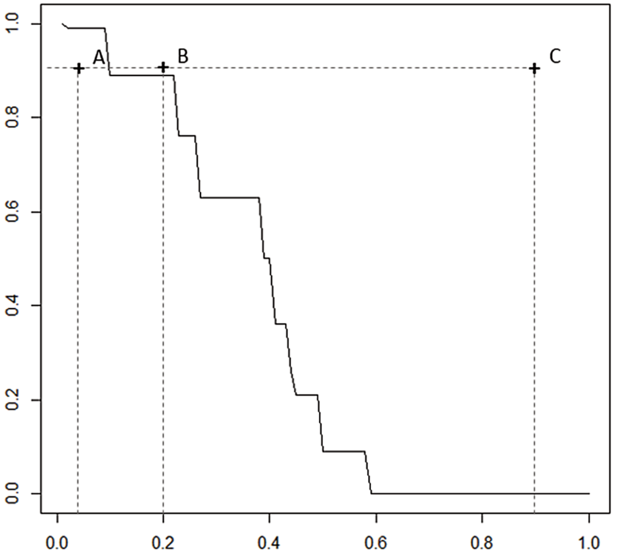


Fig. 4. A choice of policy objectives (A, B and C) line – population according to Y in decreasing order
X-axis – set of policy objectives
Y-axis – share of daily accessible total population [Mączka, 2016]

A target policy objective A (0.05) means improving the transport links to obtain daily accessibility of 0.05. It is a nonsense (assuming more accessibility is better) – the point A is already achieved by most of the population (the point is below the curve). Only $\frac{0.09}{6.62} = 0{,}01$ of total population did not achieve this goal. See Figure 3. Setting A as a goal would mean negative improvements, for example demolishing some of the infrastructure.

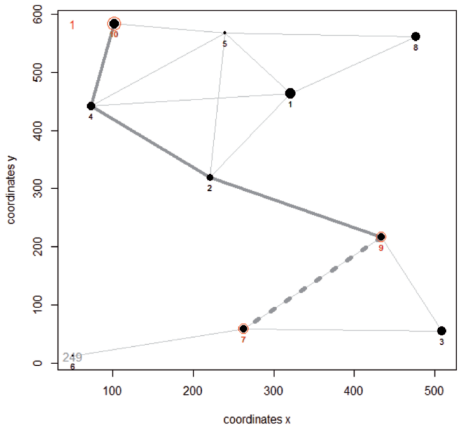
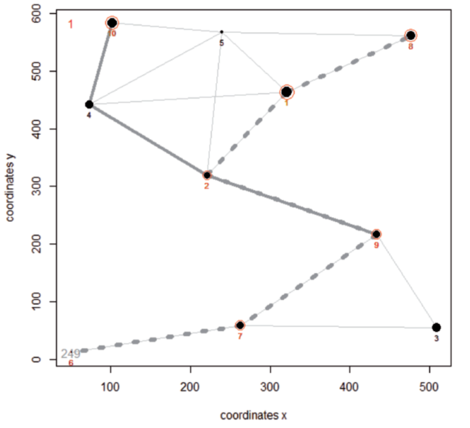
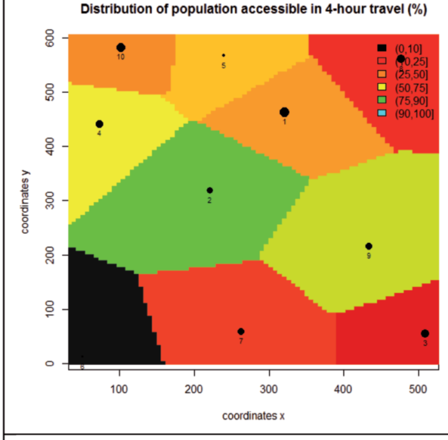
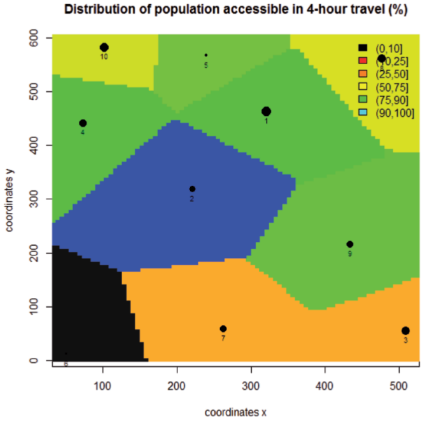
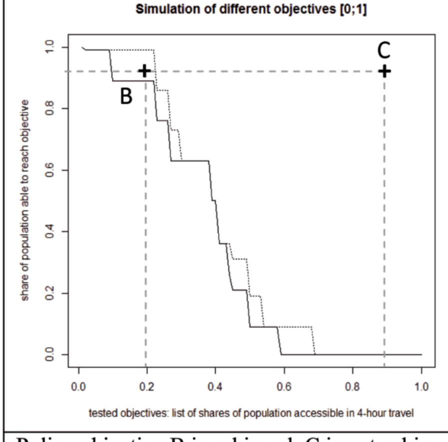
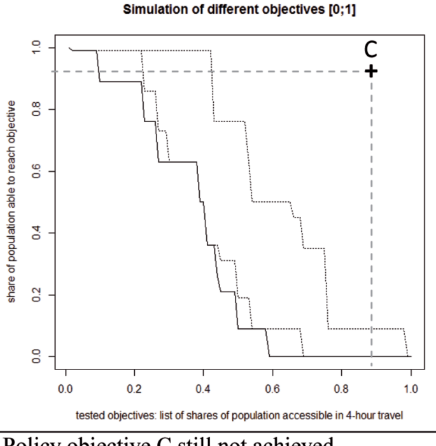
The objective B (0.20) seems to be a very easy task of for example improving quality of links of just one zone with the largest population.

The objective C (0.90) seems to be a very ambitious challenge.

Subsequent improvements of the infrastructure in the example were tested if they achieve both of the objectives (B and C). See table 7.

The first improvement connected highly populated zone 9 with another highly populated zone 7. That was enough to complete policy objective B and was estimated at a cost of 232 km of a new highway. To pursue the objective C nearly all zones links ware upgraded to higher speed. Despite incurring the costs of 577 km of a new highway (added to the previously built) the objective C was failed. In this case, some other, complementary or competitive mode of transportation is required.

Table 7. Two subsequent improvements of a random infrastructure [Mączka, 2016]

First improvement	Second improvement
	
ROM: 232 km (nodes: 9->7) of highway	ROM: 577 km (7->6, 2->1, 1->8) of highway
	
	
Policy objective B is achieved. C is not achieved.	Policy objective C still not achieved.

4. CONCLUSION

Formulating infrastructure policy of a country just by postulating a simple maximization of the numbers (number of international airports, lengths of highways or high-speed rail tracks) ignores the fact that some improvements are more significant to society than others despite their similar scale. Storing overcapacity or inadequate capacity does not contribute to social welfare, nor economy competitiveness.

A method to help shape transport policy basing on a very well-known among academia notion of daily accessibility [8] is proposed.

The Accessibility Model for Evaluation of Transport Infrastructure Policy (AMETIP) is a limited scale transportation engineering analysis. It is a cost and time efficient tool for infrastructure improvements testing. Provided an input to its graph to reflect the current transport modes infrastructure localisation and quality, the method evaluates impact of intervention in quantifiable terms and allows a formulation of optimum policy objectives. It is possible to increase the method degree of detail by adding new competing or complementary modes of travel, new nodes of network, new links, and their new quality (expressing weights in monetary terms, energy consumption or emissions units, etc.).

For the Polish environment, one of the comparable methods is the Institute of Geography and Spatial Organization of Polish Academy of Sciences (IGiPZ PAN) potential accessibility [29]. Their measure and the AMETIP daily accessibility aim to answer the same question – "what is the accessibility of all locations of transport system from location i?" The difference is the purpose and the mathematical formulation. See table 8.

Table 8. Comparison of two accessibility measures

Potential accessibility of IGIPZ PAN, 2015	Daily accessibility of AMETIP method, 2016
$D_i = M_i * f(K_{ij}) + \sum_{j=1..n,j<>i}\left(M_j * f(K_{ij})\right)$ where: M – attractiveness mass of region, e.g. population, wealth f(K) – impedance function, e.g. distance, time, cost	$daily\ accessibility = \sum_1^j population_j \quad if\ A_i > 0{,}90$ where: $A_i = \frac{accessibile\ population_i}{total\ population}$ $accessibile\ population_i = \sum_1^j pop_j \quad if\ d_{ij}{}^{(k)} < 4$ d – time of transport (shortest paths or schedule)

The IGiPZ indicator indicates a generalised potential. The AMETIP directly tests the cohesion goal achievement.

The Institute of Aviation [30] will prepare a multimodal transport graph and apply the method to simulate current and future daily accessibility levels in Poland (and European Union) [31] as well as to test the impact of small aircraft transport system (such as EPATS [32]).

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MODEL DOSTĘPNOŚCI TRANSPORTOWEJ DO TESTOWANIA ZAŁOŻEŃ POLITYKI INFRASTRUKTURALNEJ

Streszczenie

Artykuł prezentuje proste, deterministyczne narzędzie do oceny założeń polityki transportowej. Do obliczeń wymagane jest wprowadzenie kompletnego grafu reprezentującego badaną sieć transportową. Proponowana metoda wykorzystuje wskaźnik dziennej dostępności transportowej zdefiniowany przez Komisję Europejską oraz algorytm najkrótszej ścieżki Floyda-Warshalla. Wskaźnik dostępności transportowej wyróżnia grupy podróżnych na tych, którzy mają możliwość zrealizowania jednodniowej podróży w jakimkolwiek celu oraz tych, którzy nie spełniają tego warunku. Wybór odpowiednich celów publicznej polityki transportowej, takich jak na przykład zwiększenie procenta populacji, który ma możliwość zrealizowania jednodniowej podróży, jest bardziej przejrzysty i łatwiejszy do oceny. Metoda jest elastyczna i działa w darmowym środowisku R. Możliwa jest rozbudowa narzędzia przez wzrost precyzji (liczby i typów punktów węzłowych), dołożenie zasad spadku jakości połączeń (przepustowość), dodania nowych środków podróży, obliczenia kosztów podróży lub kosztów dla środowiska. Ograniczeniami rozbudowy metody jest dostępność danych i moce obliczeniowe.
Słowa kluczowe: dzienna dostępność transportowa, polityka transportowa, modelowanie przestrzenne, teoria grafów.

APPENDIX 1. FLOYD ALGORITHM

The starting point of the algorithm (iteration k = 0) is a table of edges' lengths – the adjacency matrix TIME – and an initial sequence table. Please note: infinity (Inf) is used if node is non-adjacent. Next iteration (up to the number of nodes) consist of the following steps:

1. Copy the whole first row and the whole first column to a new distance matrix from previous iteration (D0).
2. The rest of the matrix values are filled according to a condition: if a distance from origin to destination in previous iteration is greater than a sum of two values of the first row and column then use the sum (c), otherwise use the distance from the previous iteration (b). Explanation: one of the two values is a current matrix value from the first row corresponding to the considered column. The second value is, analogically, a current matrix value from the first column corresponding to the considered row. If there is infinity on both sides of the condition, use infinity (a).

Iteration k= 0

An excerpt of adjacency and weights matrix among 10 nodes

D0	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,98	2,65	Inf	Inf	3,69	Inf	Inf
2	3,51		Inf	1,38	4,98	Inf	Inf	Inf	1,69	Inf
...										

An excerpt of sequence matrix

S0	1	2	3	4	5	6	7	8	9	10
1		2	3	4	5	6	7	8	9	10
2	1		3	4	5	6	7	8	9	10
...										

Iteration k= 1

D1	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,98	2,65	Inf	Inf	3,69	Inf	Inf
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	Inf
...										

S1	1	2	3	4	5	6	7	8	9	10
1		2	3	4	5	6	7	8	9	10
2	1		3	4	5	6	7	1	9	10
...										

3. The sequence matrix values are the same, except the last situation (c), where the value is equal to the iteration number.
4. Further iterations until the last one (number of nodes) follow the same rule as in the step 2 and step 3, but the copied rows and columns correspond to the iteration number. The first two rows of the last iteration (and total length of travel) are the following (please note a fragment of copied column no. 10):

Iteration k= 10

Total length matrix

D10	1	2	3	4	5	6	7	8	9	10
1		3,51	8,76	4,89	2,65	14,22	9,85	3,69	5,20	5,43
2	3,51		5,25	1,38	4,98	10,71	6,34	7,20	1,69	2,41
...										

S10	1	2	3	4	5	6	7	8	9	10
1		2	9	2	5	9	9	8	2	5
2	1		9	4	5	9	9	1	9	4
...										

Finally, a list of paths is determined using the matrices of the last iteration. First 9 shortest paths below:

1	2	3,51	1->2
1	3	8,76	1->2->9->3
1	4	4,89	1->2->4
1	5	2,65	1->5
1	6	14,22	1->2->9->6
1	7	9,85	1->2->9->7
1	8	3,69	1->8
1	9	5,2	1->2->9
1	10	5,43	1->5->10

FLOYD ALGORITHM: All iterations for ten random nodes [Mączka, 2016]

Iteration k= 0

Adjacency and weights matrix among 10 nodes (TIME matrix)

D0	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,98	2,65	Inf	Inf	3,69	Inf	Inf
2	3,51		Inf	1,38	4,98	Inf	Inf	Inf	1,69	Inf
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,98	1,38	Inf		4,16	Inf	Inf	Inf	Inf	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	Inf	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	Inf	Inf	Inf	4,77	Inf	Inf		Inf	Inf
9	Inf	1,69	3,56	Inf	Inf	Inf	4,65	Inf		Inf
10	Inf	Inf	Inf	1,03	2,78	Inf	Inf	Inf	Inf	

Sequence matrix

S0	1	2	3	4	5	6	7	8	9	10
1		2	3	4	5	6	7	8	9	10
2	1		3	4	5	6	7	8	9	10
3	1	2		4	5	6	7	8	9	10
4	1	2	3		5	6	7	8	9	10
5	1	2	3	4		6	7	8	9	10
6	1	2	3	4	5		7	8	9	10
7	1	2	3	4	5	6		8	9	10
8	1	2	3	4	5	6	7		9	10
9	1	2	3	4	5	6	7	8		10
10	1	2	3	4	5	6	7	8	9	

Iteration k= 1

D1	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,98	2,65	Inf	Inf	3,69	Inf	Inf
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	Inf
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,98	1,38	Inf		4,16	Inf	Inf	8,67	Inf	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	Inf	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,67	4,77	Inf	Inf		Inf	Inf
9	Inf	1,69	3,56	Inf	Inf	Inf	4,65	Inf		Inf
10	Inf	Inf	Inf	1,03	2,78	Inf	Inf	Inf	Inf	

Sequence matrix

S1	1	2	3	4	5	6	7	8	9	10
1		2	3	4	5	6	7	8	9	10
2	1	0	3	4	5	6	7	1	9	10
3	1	1	0	1	1	1	7	1	9	1
4	1	2	3	0	5	6	7	1	9	10
5	1	2	3	4	0	6	7	8	9	10
6	1	1	1	1	1	0	7	1	1	1
7	1	1	3	1	1	6	0	1	9	1
8	1	1	3	1	5	6	7	0	9	10
9	1	2	3	1	1	1	7	1	0	1
10	1	1	1	4	5	1	1	1	1	0

Iteration k= 2

D2	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	Inf
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	Inf
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	Inf
9	5,20	1,69	3,56	3,07	6,67	Inf	4,65	8,89		Inf
10	Inf	Inf	Inf	1,03	2,78	Inf	Inf	Inf	Inf	

Sequence matrix

S2	1	2	3	4	5	6	7	8	9	10
1	0	2	3	2	5	6	7	8	2	10
2	1		3	4	5	6	7	1	9	10
3	2	1	0	2	2	2	7	2	9	2
4	2	2	3	0	5	6	7	2	2	10
5	1	2	3	4	0	6	7	8	2	10
6	2	1	2	2	2	0	7	2	2	2
7	2	1	3	2	2	6	0	2	9	2
8	1	1	3	2	5	6	7	0	2	10
9	2	2	3	2	2	1	7	2	0	1
10	2	1	2	4	5	2	2	2	2	0

Iteration k= 3

D3	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	Inf
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	Inf
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	Inf
9	5,20	1,69	3,56	3,07	6,67	Inf	4,65	8,89		Inf
10	Inf	Inf	Inf	1,03	2,78	Inf	Inf	Inf	Inf	

Sequence matrix

S3	1	2	3	4	5	6	7	8	9	10
1	0	2	3	2	5	3	3	8	2	3
2	1	0	3	4	5	3	3	1	9	3
3	2	1		2	2	2	7	2	9	2
4	2	2	3	0	5	3	3	2	2	10
5	1	2	3	4	0	3	3	8	2	10
6	3	3	2	3	3	0	7	3	3	3
7	2	1	3	2	2	6	0	2	9	2
8	1	1	3	2	5	3	3	0	2	3
9	2	2	3	2	2	1	7	2	0	1
10	3	3	2	4	5	3	3	3	3	0

Iteration k= 4

D4	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	5,92
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	2,41
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	9,61
9	5,20	1,69	3,56	3,07	6,67	Inf	4,65	8,89		4,10
10	5,92	2,41	Inf	1,03	2,78	Inf	Inf	9,61	4,10	

Sequence matrix

S4	1	2	3	4	5	6	7	8	9	10
1	0	2	3	2	5	3	3	8	2	4
2	1	0	3	4	5	3	3	1	9	4
3	4	4	0	2	4	4	7	4	9	4
4	2	2	3		5	3	3	2	2	10
5	1	2	3	4	0	3	3	8	2	10
6	4	4	4	3	4	0	7	4	4	4
7	4	4	3	2	4	6	0	4	9	4
8	1	1	3	2	5	3	3	0	2	4
9	2	2	3	2	2	1	7	2	0	4
10	4	4	2	4	5	3	3	4	4	0

Iteration k= 5

D5	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	5,43
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	2,41
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	7,55
9	5,20	1,69	3,56	3,07	6,67	Inf	4,65	8,89		4,10
10	5,43	2,41	Inf	1,03	2,78	Inf	Inf	7,55	4,10	

Sequence matrix

S5	1	2	3	4	5	6	7	8	9	10
1	0	2	3	2	5	3	3	8	2	5
2	1	0	3	4	5	3	3	1	9	4
3	5	5	0	5	4	5	7	5	9	5
4	2	2	3	0	5	3	3	2	2	10
5	1	2	3	4		3	3	8	2	10
6	5	5	5	5	4	0	7	5	5	5
7	5	5	3	5	4	6	0	5	9	5
8	1	1	3	2	5	3	3	0	2	5
9	2	2	3	2	2	1	7	2	0	4
10	5	4	2	4	5	3	3	5	4	0

Iteration k= 6

D6	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	5,43
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	2,41
3	Inf	Inf		Inf	Inf	Inf	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	Inf	Inf	Inf		4,37	Inf	Inf	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	7,55
9	5,20	1,69	3,56	3,07	6,67	Inf	4,65	8,89		4,10
10	5,43	2,41	Inf	1,03	2,78	Inf	Inf	7,55	4,10	

Sequence matrix

S6	1	2	3	4	5	6	7	8	9	10
1	0	2	6	2	5	3	6	8	2	5
2	1	0	6	4	5	3	6	1	9	4
3	6	6	0	6	6	5	7	6	9	6
4	2	2	6	0	5	3	6	2	2	10
5	1	2	6	4	0	3	6	8	2	10
6	5	5	5	5	4		7	5	5	5
7	5	5	3	5	4	6	0	5	9	5
8	1	1	6	2	5	3	6	0	2	5
9	2	2	3	2	2	1	7	2	0	4
10	5	4	6	4	5	3	6	5	4	0

Iteration k= 7

D7	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	5,43
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	2,41
3	Inf	Inf		Inf	Inf	9,30	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	9,30	Inf	Inf		4,37	Inf	9,02	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	7,55
9	5,20	1,69	3,56	3,07	6,67	9,02	4,65	8,89		4,10
10	5,43	2,41	Inf	1,03	2,78	Inf	Inf	7,55	4,10	

Sequence matrix

S7	1	2	3	4	5	6	7	8	9	10
1	0	2	7	2	5	7	6	8	2	5
2	1	0	7	4	5	7	6	1	9	4
3	6	6	0	6	6	7	7	6	9	6
4	2	2	7	0	5	7	6	2	2	10
5	1	2	7	4	0	7	6	8	2	10
6	5	5	7	5	4	0	7	5	7	5
7	5	5	3	5	4	6		5	9	5
8	1	1	7	2	5	7	6	0	2	5
9	2	2	3	2	2	7	7	2	0	4
10	5	4	7	4	5	7	6	5	4	0

Iteration k= 8

D8	1	2	3	4	5	6	7	8	9	10
1		3,51	Inf	4,89	2,65	Inf	Inf	3,69	5,20	5,43
2	3,51		Inf	1,38	4,98	Inf	Inf	7,20	1,69	2,41
3	Inf	Inf		Inf	Inf	9,30	4,93	Inf	3,56	Inf
4	4,89	1,38	Inf		4,16	Inf	Inf	8,58	3,07	1,03
5	2,65	4,98	Inf	4,16		Inf	Inf	4,77	6,67	2,78
6	Inf	Inf	9,30	Inf	Inf		4,37	Inf	9,02	Inf
7	Inf	Inf	4,93	Inf	Inf	4,37		Inf	4,65	Inf
8	3,69	7,20	Inf	8,58	4,77	Inf	Inf		8,89	7,55
9	5,20	1,69	3,56	3,07	6,67	9,02	4,65	8,89		4,10
10	5,43	2,41	Inf	1,03	2,78	Inf	Inf	7,55	4,10	

Sequence matrix

S8	1	2	3	4	5	6	7	8	9	10
1	0	2	7	2	5	7	6	8	2	5
2	1	0	7	4	5	7	6	1	9	4
3	8	8	0	8	8	7	7	6	9	8
4	2	2	7	0	5	7	6	2	2	10
5	1	2	7	4	0	7	6	8	2	10
6	8	8	7	8	8	0	7	5	7	8
7	8	8	3	8	8	6	0	5	9	8
8	1	1	7	2	5	7	6		2	5
9	2	2	3	2	2	7	7	2	0	4
10	5	4	7	4	5	7	6	5	4	0

Iteration k= 9

D9	1	2	3	4	5	6	7	8	9	10
1		3,51	8,76	4,89	2,65	14,22	9,85	3,69	5,20	5,43
2	3,51		5,25	1,38	4,98	10,71	6,34	7,20	1,69	2,41
3	8,76	5,25		6,63	10,23	9,30	4,93	12,45	3,56	7,66
4	4,89	1,38	6,63		4,16	12,09	7,72	8,58	3,07	1,03
5	2,65	4,98	10,23	4,16		15,69	11,32	4,77	6,67	2,78
6	14,22	10,71	9,30	12,09	15,69		4,37	17,91	9,02	13,12
7	9,85	6,34	4,93	7,72	11,32	4,37		13,54	4,65	8,75
8	3,69	7,20	12,45	8,58	4,77	17,91	13,54		8,89	7,55
9	5,20	1,69	3,56	3,07	6,67	9,02	4,65	8,89		4,10
10	5,43	2,41	7,66	1,03	2,78	13,12	8,75	7,55	4,10	

Sequence matrix

S9	1	2	3	4	5	6	7	8	9	10
1	0	2	9	2	5	9	9	8	2	5
2	1	0	9	4	5	9	9	1	9	4
3	9	9	0	9	9	7	7	9	9	9
4	2	2	9	0	5	9	9	2	2	10
5	1	2	9	4	0	9	9	8	2	10
6	9	9	7	9	9	0	7	9	7	9
7	9	9	3	9	9	6	0	9	9	9
8	1	1	9	2	5	9	9	0	2	5
9	2	2	3	2	2	7	7	2		4
10	5	4	9	4	5	9	9	5	4	0

Iteration k= 10

Total length matrix

D10	1	2	3	4	5	6	7	8	9	10
1		3,51	8,76	4,89	2,65	14,22	9,85	3,69	5,20	5,43
2	3,51		5,25	1,38	4,98	10,71	6,34	7,20	1,69	2,41
3	8,76	5,25		6,63	10,23	9,30	4,93	12,45	3,56	7,66
4	4,89	1,38	6,63		3,81	12,09	7,72	8,58	3,07	1,03
5	2,65	4,98	10,23	3,81		15,69	11,32	4,77	6,67	2,78
6	14,22	10,71	9,30	12,09	15,69		4,37	17,91	9,02	13,12
7	9,85	6,34	4,93	7,72	11,32	4,37		13,54	4,65	8,75
8	3,69	7,20	12,45	8,58	4,77	17,91	13,54		8,89	7,55
9	5,20	1,69	3,56	3,07	6,67	9,02	4,65	8,89		4,10
10	5,43	2,41	7,66	1,03	2,78	13,12	8,75	7,55	4,10	

Sequence matrix

S10	1	2	3	4	5	6	7	8	9	10
1	0	2	9	2	5	9	9	8	2	5
2	1	0	9	4	5	9	9	1	9	4
3	9	9	0	9	9	7	7	9	9	9
4	2	2	9	0	10	9	9	2	2	10
5	1	2	9	10	0	9	9	8	2	10
6	9	9	7	9	9	0	7	9	7	9
7	9	9	3	9	9	6	0	9	9	9
8	1	1	9	2	5	9	9	0	2	5
9	2	2	3	2	2	7	7	2	0	4
10	5	4	9	4	5	9	9	5	4	

FLOYD ALGORITHM: A complete shortest paths list for ten random nodes [Mączka, 2016]

	origin	destination	length	path		origin	destination	length	path
1	1	2	3,51	1->2	46	6	1	14,22	6->7->9->1
2	1	3	8,76	1->2->9->3	47	6	2	10,71	6->7->9->2
3	1	4	4,89	1->2->4	48	6	3	9,3	6->7->3
4	1	5	2,65	1->5	49	6	4	12,09	6->7->9->4
5	1	6	14,22	1->2->9->6	50	6	5	15,69	6->7->9->5
6	1	7	9,85	1->2->9->7	51	6	7	4,37	6->7
7	1	8	3,69	1->8	52	6	8	17,91	6->7->9->8
8	1	9	5,2	1->2->9	53	6	9	9,02	6->7->9
9	1	10	5,43	1->5->10	54	6	10	13,12	6->7->9->10
10	2	1	3,51	2->1	55	7	1	9,85	7->9->1
11	2	3	5,25	2->9->3	56	7	2	6,34	7->9->2
12	2	4	1,38	2->4	57	7	3	4,93	7->3
13	2	5	4,98	2->5	58	7	4	7,72	7->9->4
14	2	6	10,71	2->9->6	59	7	5	11,32	7->9->5
15	2	7	6,34	2->9->7	60	7	6	4,37	7->6
16	2	8	7,2	2->1->8	61	7	8	13,54	7->9->8
17	2	9	1,69	2->9	62	7	9	4,65	7->9
18	2	10	2,41	2->4->10	63	7	10	8,75	7->9->10
19	3	1	8,76	3->9->1	64	8	1	3,69	8->1
20	3	2	5,25	3->9->2	65	8	2	7,2	8->1->2
21	3	4	6,63	3->9->4	66	8	3	12,45	8->1->2->9->3
22	3	5	10,23	3->9->5	67	8	4	8,58	8->1->2->4
23	3	6	9,3	3->7->6	68	8	5	4,77	8->5
24	3	7	4,93	3->7	69	8	6	17,91	8->1->2->9->6
25	3	8	12,45	3->9->8	70	8	7	13,54	8->1->2->9->7
26	3	9	3,56	3->9	71	8	9	8,89	8->1->2->9
27	3	10	7,66	3->9->10	72	8	10	7,55	8->5->10
28	4	1	4,89	4->2->1	73	9	1	5,2	9->2->1
29	4	2	1,38	4->2	74	9	2	1,69	9->2
30	4	3	6,63	4->2->9->3	75	9	3	3,56	9->3
31	4	5	3,81	4->10->5	76	9	4	3,07	9->2->4
32	4	6	12,09	4->2->9->6	77	9	5	6,67	9->2->5
33	4	7	7,72	4->2->9->7	78	9	6	9,02	9->7->6
34	4	8	8,58	4->2->8	79	9	7	4,65	9->7
35	4	9	3,07	4->2->9	80	9	8	8,89	9->2->8
36	4	10	1,03	4->10	81	9	10	4,1	9->2->4->10
37	5	1	2,65	5->1	82	10	1	5,43	10->5->1
38	5	2	4,98	5->2	83	10	2	2,41	10->4->2
39	5	3	10,23	5->2->9->3	84	10	3	7,66	10->4->9->3
40	5	4	3,81	5->10->4	85	10	4	1,03	10->4
41	5	6	15,69	5->2->9->6	86	10	5	2,78	10->5
42	5	7	11,32	5->2->9->7	87	10	6	13,12	10->4->9->6
43	5	8	4,77	5->8	88	10	7	8,75	10->4->9->7
44	5	9	6,67	5->2->9	89	10	8	7,55	10->5->8
45	5	10	2,78	5->10	90	10	9	4,1	10->4->9