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Advantages Of Regional Infectious Hospital Points In North Macedonia During The COVID-19 Pandemic In Weighted C-Centers

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Abstract- Graph theory is a field of study that has a wide range of applications in many different areas. This research focuses on the use of Floyd's Algorithm for modeling and finding the weighted c-centers in the eight regions of North Macedonia, which correspond to the planning regions defined by the decision of the Assembly of North Macedonia, dated September 29, 2009.

In the context of the SARS-CoV-2 (COVID-19) pandemic, where chaos and challenges have escalated globally, the application of graph theory is essential in providing mathematical solutions to health emergency problems, and North Macedonia has not been an exception to the resulting challenges. The increase in the number of infected individuals and the issues of overcrowding in a hospital center were among the most critical aspects of the situation. This research aims to focus on the importance of establishing infectious hospital points in several key centers, which would have provided faster, more efficient, and financially less costly medical services. This paper offers an effort to find mathematical solutions that would improve preparedness and response to future pandemics. The aim of this paper is to contribute to the design of efficient planning for health emergency situations, addressing challenges related to the strategic placement of hospital resources during crisis moments. The data on the number of infected individuals are official data, obtained from the Ministry of Health of North Macedonia.

Keywords- Graphs, Covid-19, North Macedonia, Floyd's Algorithm, Advantages, C-Centres.

1. Introduction

The study of facility placement has been an important field of research for many decades and has wide application in modern society and today's economy. Starting from the formulation of the Location Problem by Weber in 1909, this problem has become a fundamental challenge in industrial engineering and management sciences. The main requirement is finding optimal locations for various facilities, including factories, hospitals, and important infrastructure, based on the demands and needs of a wide group of clients.

The challenges in this field are numerous and have evolved over time, including specific periods such as the COVID-19 pandemic. The SARS-CoV-2 (COVID-19) pandemic has made the location of facilities, especially hospitals and health centers, of extraordinary importance for responding to health emergencies and using health resources efficiently. To tackle this challenge, our paper uses an advanced data optimization algorithm to identify suitable locations for treating patients in future pandemics. The

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study of facility placement is an important research field with various applications, having a significant impact on improving efficiency and response to the needs of society and the economy.

2. The main concepts of Graph Theory

2.1 Definition of a graph. Examples

Let V be a non-empty finite set: V={v_1, v_2, …,v_n}. Such a set can be represented by a diagram, where its elements are denoted by points. Each such point is called a vertex. If two of its elements v_i , v_j , not necessarily distinct, are considered together, then those points are connected in the diagram with straight or curved line segments, where one end is point vi and the other is point vj. Such a segment is called an edge and is denoted v_iv_j, where the order does not matter. Note that two such points can be connected with more than one edge, and when the ends are the same point, the edge is represented by a loop.

Let E be a set of edges with endpoints in the vertices of set V.

Definition 2.1.1. Under the above conditions, the pair G=(V,E), where V is a non-empty finite set of vertices, and E is a finite set of edges, is called a graph.

Definition 2.1.2.

- The vertices of an edge are called its endpoints;
- Two vertices are called neighbors if there exists an edge that connects them;
- Two edges are called incident if they have a common vertex;
- A graph is called simple if it has no loops;
- A graph that has vertices but no edges is called an empty graph.

Definition 2.1.3 The Graph $H=(V_H, E_H)$ is called a subgraph of the graph $G=(V_G, E_G)$, if $V_H \subseteq V_G$ and $E_H \subseteq E_G$. We denote this as $H \leq G$.

Definition 2.1.4 A directed graph is an ordered pair

$G=(V, E)$, where V is a non-empty finite set, and E is a subset of the Cartesian product $V \times V$.

If the element (x_i,x_j) is part of E, p times, then graph G is called a p-graph. Consequently, if each pair (x_i,x_j) appears only once in E, then graph G is called a 1-graph. [1]

Definition 2.1.5. An ordered system of vertices $(x_0, x_1, x_2, ..., x_r)$, $r \geq 1$ of graph $G=(V, E)$ such that each edge x_ix_{i+1}, for $i = 0, 1, ..., r-1$, belongs to the graph G, is called a path in G. The vertex x_0 *i*s called the start of the path, while x_r is called the end of the path.

Definition 2.1.6. Let $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$ be given graphs, where $V1 \cap V2 = \emptyset$ (they are disjoint). The Graph $G = (V, E) = G_1 \cup G_2$, where $V = V_1 \cup V_2$ and $E = E_1 \cup E_2$ is called the union of graphs $G_1$and G_2.

Definition 2.1.7. A graph is called connected if it is not the union of two graphs. Otherwise, we say that the graph is disconnected.

To be specific, A graph that is in one piece, so that any two vertices are connected by a path, is a connected graph; a graph in more than one piece is a disconnected graph. [2].

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2.2. Weighted Graphs. The Minimal Distance – The Shortest Path Problem

Let $G=(V, E)$ be a directed graph, associated with which is a function (mapping) $W:E\rightarrow R_0^+$, that assigns to each edge $e\in E$ exactly one non-negative real number $W(e)$, which is called the weight of the edge or the weighted length of the edge or the weighted distance between the endpoints of the edge If the edge is $e=(v_i, v_j)$, then we denote its weighted length as:

$$W_{i,j}: W(v_i, v_j)= W_{i,j} .$$

Definition 2.2.1. A graph G equipped with a weight function W on its edges is called a *weighted graph* and is denoted by G^W .

For a subgraph H of the graph G^W, the number $W(H) = \sum_{e\in E(H)} w(e)$ is called the total weight of the subgraph H.

In particular, if H is a path $P = (v_{i_1}, v_{i_2},..., v_{i_p})$ from G^W , then the sum $W(P) = \sum_{k=1}^{p-1} W_{i_k,i_{k+1}}$ is called the *weighted length* (short *length*) of the path P. Every isolated vertex of the graph G^W is considered as a path with length 0.

In a directed graph, there can be several paths starting at v_i and ending at v_j. Of interest is identifying those paths that have the smallest length, in other words, finding the *shortest path* starting at a vertex v_i and ending at vertex v_j. The length of the shortest path starting at v_i and ending at v_j is called the minimal distance between vertices v_i and v_j and is denoted $d(v_i,v_j)$, i.e.

$$d(v_i, v_j) = min\{W(P)|P \text{ is a path starting at } v_i \text{ and ending at } v_j\}$$

It is clear that the shortest paths are sought among the elementary paths. Since the number of vertices in the graph is finite, the number of different elementary paths between two vertices is also finite. This makes it possible to find the shortest paths, but the aim is to find the best method, which is provided by certain algorithms

Note. When the graph is undirected, as in the case of the mathematical model for constructing a highway with minimal cost between two cities (see [1], example on page 270), taking the cost as the weight and considering that the highway functions in both directions, such a graph is treated as a directed graph with bidirectional edges. [3],[4]

2.3. Floyd's Algorithm

This algorithm solves the problem of minimal distances and shortest paths between every two vertices of a 1-graph with a discrete distance matrix $A=(l_{ij})_{nxm.}$

Initial Step: We take the matrices $A_0=(l_{ij}^{(0)})_{nxm}$ and $S_0=(s_{ij}^{(0)})_{nxm}$ such that $l_{ij}^{(0)}=l_{ij}$ and $s_{ij}^{(0)}=j$ for every $i,j=1,2,\dots,n$. We set k=l and proceed to the general step.

General Step (k): We find the matrices $A_k=(l_{ij}^{(k)})_{nxm}$ and $S_k=(s_{ij}^{(k)})_{nxm}$ where:

$$l_{ij}^{(k)} = \begin{cases} \min(l_{ij}^{(k-1)}, l_{ik}^{(k-1)} + l_{kj}^{(k-1)}) \; for\ i \neq k, j \neq k \\ l_{ij}^{(k-1)} \quad for\ i = k\ and|or\ j = k \end{cases}$$

$$S_{ij}^{(k)} = \begin{cases} k\ p\ddot{e}r\ i, j \neq k\ such\ that\ l_{ik}^{(k-1)} + l_{kj}^{(k-1)} < l_{ij}^{(k-1)} \\ S_{ij}^{(k)} \quad in\ the\ opposite\ case \end{cases}$$

We set k equal to *(k+1)* and repeat the general step until k takes the value of n. The matrix An found at the end of n- steps is the matrix of minimal distances between the vertices of the graph, i.e., $An=A^*$.[5],[6]

2.4. Concepts of Centers in Graphs

In practice, it is often necessary to find the 'most suitable' place to build an object that serves several peripheral points, which may be populated centers or various points that require service. For example, in a given region, where is it best to place a healthcare facility, a social-cultural center, or a shopping center that serves populated centers, for a telegraph network, where is it best to place the information processing center (central). Depending on the criterion of optimality for the position of this object, we examine two types of such problems:

- In the first type are those problems where the most suitable place for the object is considered to be the one from which the greatest of the minimal distances from the object to the peripheral points is the smallest possible. This type includes the problem of placing a social-cultural or healthcare facility.
- In the second type of problems, the most suitable place for the object is the one from which the sum of the lengths of all the shortest paths connecting the object to the peripheral points is the smallest possible. It is more economical for the total length of the conduits connecting the points of the telegraph network to the central office to be minimal; therefore, this problem falls under the second type. [4]

2.4.1. Centers in Graphs

If we take a connected graph G=(V,E) me n kulme, with

n vertices, each edge $u \in E$ is assigned a non-negative number l(u). We denote $l^*(x_i,x_j)$ as the minimal distance from x_i to x_j.

- The vertex $x_c \in V$ such that for every i=1,2,..,n satisfies the inequaity:

  $max_{1\le j\le n} l^*(x_c, x_j) \le max_{1\le j\le n} l^*(x_i, x_j)$ is called the *c-center of a graph*.

  In other words, the c-center is the vertex where:

$$min_{1\le i\le n}\{max_{1\le j\le n} l^*(x_i, x_j)\}$$

Let's assume that for every vertex $x_j \in V$, we are given a positive number w_j which we call its weight. In different problems, w_j has different meanings; for example In the placement of a service center in an area, w_j may also indicate the number of inhabitants of the i-th settlement.

- A weighted *c-center* of the graph G is any vertex $x_c \in V$ such that:

$$max_{1\le j\le n}\{w_j\ l^*(x_c, x_j)\} \le max_{1\le j\le n}\{w_j\ l^*(x_i, x_j)\}, \text{ for each i=1,2,..,n}$$

In the above definitions, a center exists only when the left-hand sides of the inequalities are finite numbers. Otherwise, it is stated that the graph does not have a center, or a c-center. It is clear that G will have a center if and only if there is at least one vertex from which every other vertex can be reached via paths in G.

In the above definitions, the vertices are considered to have the same 'rights.' In practice, this consideration is not always appropriate. For example, in the placement of a healthcare or social-cultural facility serving several populated centers, the number of inhabitants of each residential center must also be taken into account, meaning that the service facility should be as close as possible to the centers with more inhabitants. [5], [6], [7], [8].

2.4.2. A way to find the centers

All four types of centers defined above can be easily found using the matrix A^*, which is found with the help of Floyd's Algorithm.

i) For simple centers, we add a column to matrix A where we place the maximum element of each row. The vertex corresponding to the smallest element of the added column represents the c-center.

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ii) To obtain the weighted c-center, we first multiply the columns of matrix $A*$ by the weights w_j of the vertices respectively, and then proceed in the same way as in point i).

3. Regional C-centers of North Macedonia during the Pandemic

3.1 Skopje Region

The Skopje Region consists of the City of Skopje and seven municipalities around it

1. City of Skopje,

2. Aračinovo

3. Zelenikovo

4. Ilinden

5. Petrovec

6. Sopište

7. Studeničani

8. Čučer-Sandevo

The Skopje Region is the region with the greatest economic potential, development, and influence in the country.

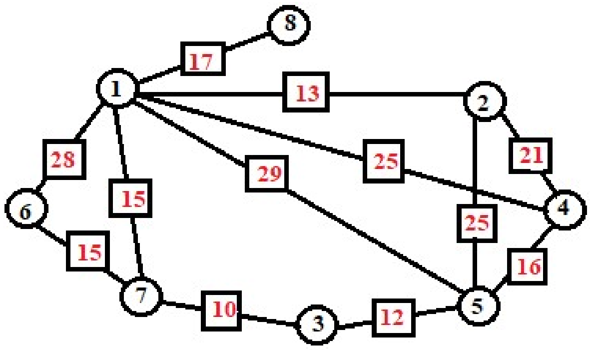

Figure 1 Graph of the Skopje Region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges. In Table 2, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

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Table 1. The number of residents, infected and dead in the Skopje region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1	City of Skopje	528297	151414	3058
2	Araçinovo	12676	531	28
3	Zelenikovo	3361	742	20
4	Ilinden	17435	3982	79
5	Petrovec	9150	1378	30
6	Sopishte	6713	1464	35
7	Studeniçani	21970	1041	51
8	Çuçer Sandevo	9200	1209	26
		528297	151414	3058

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 2. The final c-center table for the Skopje region

1	0	6903	18550	99550	39962	40992	15615	20553	99550
2	1968382	0	27454	83622	34450	60024	29148	36270	1968382
3	3785350	19647	0	111496	16536	36600	10140	50778	3785350
4	3785350	11151	20776	0	22048	77592	39558	50778	3785350
5	4391006	13275	8940	63712	0	54168	22902	55614	4391006
6	4239592	21771	18550	211046	50986	0	15615	54405	4239592
7	2271210	14868	7420	151316	30316	21960	0	38688	2271210
8	2574038	15930	31164	167244	63388	65880	33312	0	2574038

From Table 2, it is observed that the percentage of infected individuals in the Skopje Region is 28.66%, while the mortality rate is 2.02%.

From Table 2, it is observed that *the weighted c-center* is vertex 1, which corresponds to the city of *Skopje*.

3.2. North-Eastern Region

The northeastern region consists of six municipalities:

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1. Kratovo
2. Kriva Palanka
3. Kumanovo
4. Lipkovo
5. Rankovce
6. Staro Nagoričane

The north-eastern region is a region with great economic potential, rich in natural and historical resources.

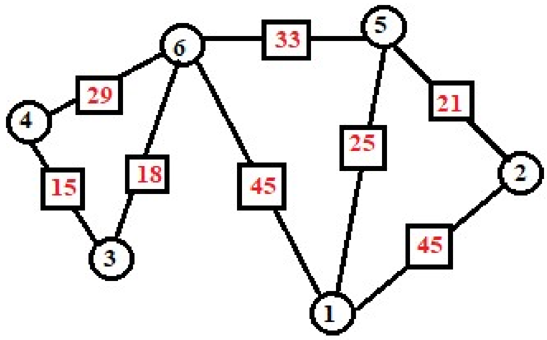

Figure 2. Graph of the North-Eastern Region

Where the circles with numbers represent municipalities, and rectangles represent distances or weights of the edges.

In Table 3, we have presented the data for the ordinal numbers of vertices and the number of residents according to the 2021 census, the total number of Covid-19 infections during the pandemic, and among them, the number of deaths.

Table 3. The number of residents, infected and dead in the North-Eastern Region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1.	Kratovo	7545	1144	38
2.	Kriva Palanka	18059	2424	117
3.	Kumanovo	98104	16984	551
4.	Lipkovo	22308	1117	83
5.	Rankovce	3465	253	14
6.	Staro Nagoričane	3501	338	17
		152982	22260	820

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Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 4. The final c-center table for the North-Eastern Region

1	0	109080	1069992	82658	6325	15210	1069992
2	51480	0	1222848	92711	5313	18252	1222848
3	72072	174528	0	16755	12903	6084	174528
4	84656	201192	254760	0	15686	9802	254760
5	28600	50904	866184	69254	0	11154	866184
6	51480	130896	305712	32393	8349	0	305712

From Table 3, it is observed that the percentage of infected individuals in the North-Eastern region is 14.55%, while the mortality rate is 3.68%.

From Table 4, it is observed that *the weighted c-center* is vertex 3, which corresponds to the city of *Kumanovo*.

3.3. Polog Region

The Polog Region consists of nine municipalities:

1. Bogovinje
2. Brvenica
3. Vrapčishte
4. Gostivar
5. Zhelino
6. Jegunovce
7. Mavrovo & Rostushe
8. Tearce
9. Tetovo

The region of Polog is a region with great industrial, economic and tourist potential.

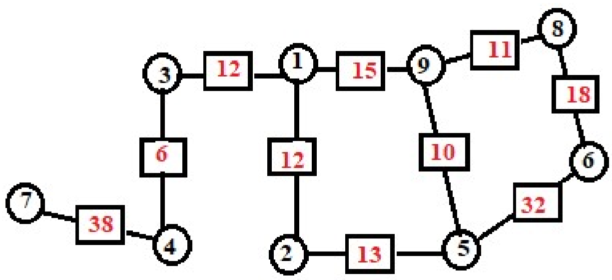

Figure 3. Graph of the Polog Region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges.

In Table 5, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

Table 5. The number of residents, infected and dead in the Polog Region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1.	Bogovino	22906	993	90
2.	Brvenica	13645	1082	38
3.	Vrapčiste	19842	1091	68
4.	Gostivar	59770	8619	344
5.	Zhelino	18988	592	58
6.	Jegunovce	8895	892	31
7.	Mavrovo&Rostushe	5042	560	32
8.	Tearce	17694	1090	38
9.	Tetovo	84770	9621	353
		251552	24540	1052

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 6. The final c-center table for the Polog Region

1	0	12984	13092	155142	14800	39248	31360	28340	144315	155142
2	11916	0	26184	258570	7696	40140	38080	37060	221283	258570
3	11916	25968	0	51714	21904	49952	24640	41420	259767	259767
4	17874	32460	6546	0	25456	55304	21280	47960	317493	317493
5	24825	14066	40367	370617	0	28544	45360	22890	96210	370617
6	43692	48690	61096	534378	18944	0	56000	19620	279009	534378
7	55608	73576	48004	327522	47952	89200	0	89380	683091	683091
8	25818	36788	41458	379236	12432	16056	45920	0	105831	379236
9	14895	24886	29457	284427	5920	25868	39760	11990	0	284427

From Table 5, it is observed that the percentage of infected individuals in the Polog region is 9.76%, while the mortality is 4.29%.

From Table 6, it is observed that *the weighted c-center* is vertex 1, which corresponds to the municipality of *Bogovino*.

3.4. Region of Pellagonia

The western region consists of nine municipalities:

1. Bitola
2. Demir Hisar
3. Krivogashtani
4. Krushevo
5. Mogilla
6. Prilep
7. Resen
8. Novaci
9. Dolneni

The region of Pellagonia is a region with great industrial, economic and tourist potential.

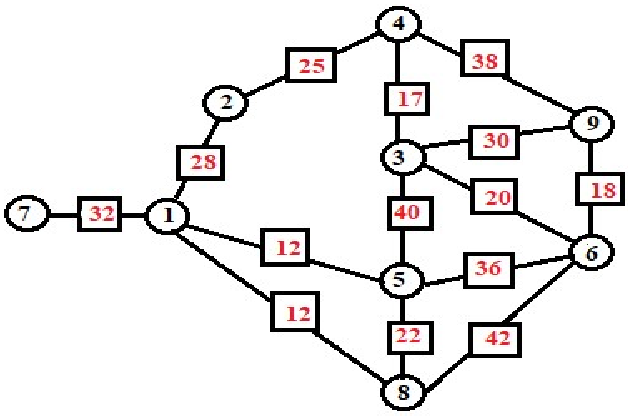

Figure 4. Graph of the Pellagonia Region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges.

In Table 7, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

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Table 7. The number of residents, infected and dead in the Pellagonia Region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1.	Bitola	85164	17833	479
2.	Demir Hisar	7260	944	43
3.	Krivogashtani	5167	622	32
4.	Krushevo	8385	1042	46
5.	Mogillo	5283	307	22
6.	Prilep	69025	14755	535
7.	Resen	14373	3044	67
8.	Novaci	2648	216	18
9.	Dollneni	13126	646	47
		210431	39409	1289

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 8. The final c-center table for the Pellagonia Region

1	0	26432	32344	55226	3648	708240	97408	2592	42636	708240
2	499324	0	26124	26050	12280	914810	182640	8640	40698	914810
3	927316	39648	0	17714	12280	295100	255696	13392	19380	927316
4	945149	23600	10574	0	17499	545935	258740	14040	24548	945149
5	213996	37760	24880	59394	0	531180	133396	4752	34884	531180
6	855984	58528	12440	38554	11052	0	243520	9072	11628	855984
7	570656	56640	52248	88570	13508	1180400	0	9504	63308	1180400
8	213996	37760	38564	67730	6754	619710	133936	0	38760	619710
9	1176978	59472	18660	39596	16578	265590	298312	12960	0	1176798

From Table 7, it is observed that the percentage of infected individuals in the Pellagonia region is 18.73%, while the mortality rate is 3.27%.

From Table 8, it is observed that *the weighted c-center* is vertex 5, which corresponds to *Mogillo*.

3.5. South-Eastern Region

The south region consists of ten municipalities:

1. Bogdanci
2. Bosillovo
3. Vallandovo
4. Vasilevo
5. Gevgelija
6. Dojran
7. Konçe
8. Novo Selo
9. Radovish
10. Strumica

The south-eastern region is a region with great industrial, economic and tourist potential.

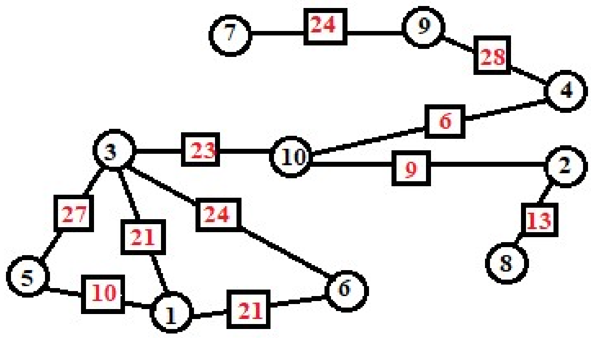

Figure 5. Graph of the South-Eastern Region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges.

In Table 9, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants

according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

Table 9. The number of residents, infected and dead in the South-Eastern Region

No.	Municipality	No. residen ts 2021	Total infected	Of them dead
1.	Bogdanci	7339	1117	30
2.	Bosillovo	11508	878	46
3.	Vallandovo	10508	1616	52
4.	Vasilevo	10552	547	30
5.	Gevgelija	21582	4901	133
6.	Dojran	3084	372	8
7.	Konče	2725	107	9
8.	Novo Sello	6972	591	46
9.	Radovish	24122	2734	97
10.	Strumica	49995	6782	280
		148387	19645	731

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 10. The final c-center table for the South-Eastern Region

1	0	46534	33936	26083	49010	7812	10807	39006	210518	120296	210518
2	59201	0	51712	7658	289159	20832	7062	7683	114828	24606	289159
3	24357	28096	0	15316	132327	8928	8560	26595	153104	62882	153104
4	54733	12292	45248	0	269555	19344	5564	15957	76552	13670	269555
5	11170	51802	43632	30085	0	11532	11449	42552	226922	136700	226922
6	24357	49168	38784	28444	151931	0	11128	40779	218720	128498	218720
7	112817	57948	129280	28444	524407	38688	0	46689	65616	155838	524407
8	73722	11414	72720	14769	352872	25668	8453	0	150370	60148	352872
9	86009	36876	90496	15316	406783	29760	2568	32505	0	90222	406783
10	49148	7902	37168	2735	245050	17484	6099	13002	90222	0	245050

From Table 9, it is observed that the percentage of infected individuals in the South-Eastern Region is 13.24%, while the mortality rate is 3.72%.

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From Table 10, it is observed that *the weighted c-center* is vertex 3, which corresponds to the municipality of *Valandovo.*

3.6. South-Western Region

The south-western region consists of nine municipalities:

1. Vevčani
2. Debar
3. Debarca
4. Kičevo
5. Makedonski Brod
6. Ohrid
7. Plasnica
8. Struga
9. Centar Zhupa

The western region is a region with great industrial, economic and tourist potential.

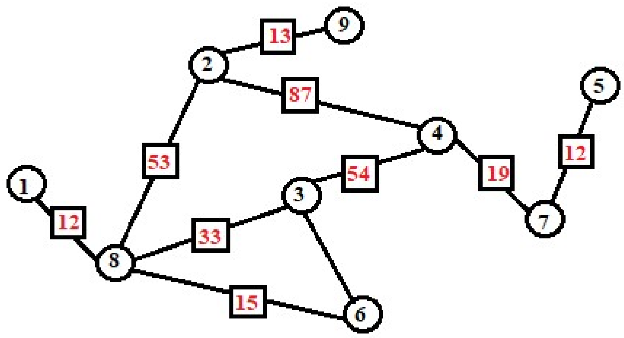

Figure 6. Graph of the South-Western Region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges.

In Table 11, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

Table 11. The number of residents, infected and dead in the South-Western Region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1.	Vevčani	2359	541	18
2.	Debar	15412	1540	53
3.	Debarca	3719	300	29
4.	Kičevo	39669	6080	234
5.	Makedonski Brod	5889	667	26
6.	Ohrid	51428	10353	400
7.	Pllasnica	4222	143	7
8.	Struga	50980	4669	290
9.	Centar Zhupa	3720	281	30
		177398	24574	1087

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 12. The final c-center table for the South-Western Region

1	0	101100	13500	601920	86710	279531	16874	56028	21918	601920
2	35165	0	25800	528960	78706	704044	15158	247457	3653	704044
3	24345	132440	0	328320	56695	383061	10439	154077	27819	383061
4	53559	133980	16200	0	20677	942123	2717	406203	28100	942123
5	70330	181720	25500	188480	0	1263066	1716	550942	36811	1263066
6	14607	104720	11100	553280	81374	0	15730	70035	22761	553280
7	63838	163240	21900	115520	8004	1138830	0	494914	33439	1138830
8	6492	81620	9900	528960	78706	155295	15158	0	18546	528960
9	42198	20020	29700	608000	87377	838593	17017	308154	0	838593

From Table 11, it is observed that the percentage of infected individuals in the South-Wastern Region is 13.85%, while the mortality rate is 4.42%.

From Table 12, it is observed that *the weighted c-center* is vertex 3, which corresponds to the municipality of *Debarca.*

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3.7. Eastern Region

The eastern region consists of eleven municipalities:

1. Berovo
2. Vinica
3. Delčevo
4. Zrnovci
5. Karbinci
6. Kočani
7. Makedonska Kamenica
8. Pehčeva
9. Probishtip
10. Ceshinovo-Obleshevo
11. Shtip

The eastern region is a region with great industrial, economic and tourist potential.

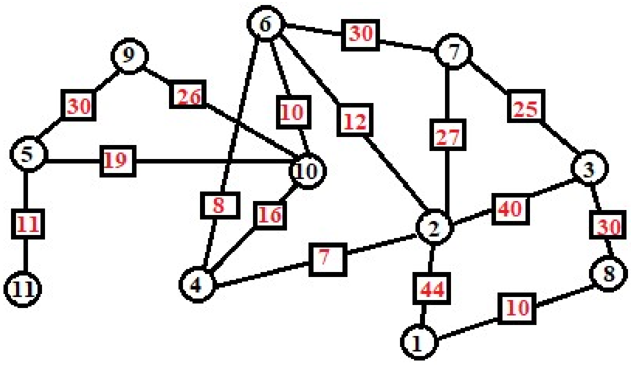

Figure 7. Graph of the Eastern Region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges.

In Table 13, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

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Table 13. The number of residents, infected and dead in the Eastern Region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1.	Berovo	10890	1909	61
2.	Vinica	14475	1486	69
3.	Dellčevo	13585	2210	75
4.	Zrnovci	2086	212	10
5.	Karbinci	3420	244	7
6.	Koçani	31602	4789	184
7.	Makedonska Kamenica	6439	540	25
8.	Pehçevo	3983	522	17
9.	Probishtip	13417	1308	54
10.	Çeshinovo-Obleshevo	5471	559	36
11.	Shtip	44866	8620	242
		150234	22399	780

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 14. The final c-center table for the Eastern Region

1	0	65384	88400	10812	20704	268184	35100	5220	12063	36894	827520	827520
2	83996	0	88400	1484	10004	57468	14580	28188	62784	12298	448240	448240
3	76360	59440	0	9964	19764	249028	13500	15660	30454	34658	793040	793040
4	97359	10402	103870	0	8540	38312	18360	31842	89434	8944	396520	396520
5	162265	60926	179010	7420	0	138881	31860	49590	93240	10621	94820	179010
6	160904	17832	114920	1696	7076	0	16200	34452	47898	5590	344800	344800
7	124085	40122	55250	7208	14396	143670	0	28710	86328	22360	603400	603400
8	19090	80244	66300	12932	23180	316074	29700	0	133416	42484	913720	913720
9	175628	71328	194480	8904	7320	172404	35640	33260	0	14534	353420	353420
10	125994	32692	137020	3392	4636	47890	21600	37092	34008	0	258600	258600
11	183264	77272	203320	9752	2684	191560	37800	53332	53628	16770	0	203320

From Table 13, it is observed that the percentage of infected individuals in the Eastern Region is 14.91%, while the mortality rate is 3.48%.

From Table 14, it is observed that *the weighted c-center* is vertex 5, which corresponds to the municipality of *Karbinci.*

3.8. Vardar Region

The Vardar Region consists of nine municipalities:

1. Velesi
2. Gradsko
3. Demir Kapija
4. Kavadarci
5. Lozovo
6. Negotino
7. Rosoman
8. Sveti Nikole
9. Çashka

The Vardar region is a region with great industrial, economic and tourist potential.

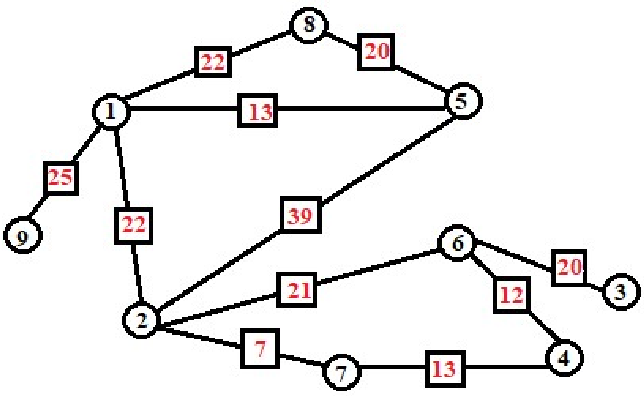

Figure 8. Graph of the Vardar region

Where the circles with numbers represent the municipalities, and the rectangles represent the distances or weights of the edges.

In Table 15, we have presented the data for the ordinal numbers of the vertices and the number of inhabitants according to the 2021 census, the total number of Covid-19 infections during the pandemic, and the number of deaths from these infections.

Table 15. The number of residents, infected and dead in the Vardar region

No.	Municipality	No. residents 2021	Total infected	Of them dead
1.	Veles	48463	10109	308
2.	Gradsko	3233	341	18
3.	Demir Kapija	3777	638	20
4.	Kavadarci	35733	11532	263
5.	Llozovo	2264	153	7
6.	Negotino	18194	4248	100
7.	Rosoman	3796	924	25
8.	Sveti Nikole	15320	2655	73
9.	Çashka	7942	405	21
		138722	31005	835

Using Floyd's Algorithm we find $A*$ and proceed based on the explanations provided in 2.4.1, 2.4.2.i), ii) This gives us

Table 16. The final c-center table for the Vardar Region

1	0	7502	40194	484344	1989	182664	26796	58410	10125	484344
2	222398	0	26158	203604	5355	89208	6468	116800	19035	230640
3	636867	13981	0	369024	11628	84960	41580	225675	35640	636867
4	424578	6820	20416	0	8415	50976	12012	169920	27135	424578
5	131417	11935	48488	634260	0	237888	38808	53100	15390	634260
6	434687	7161	12760	138384	8568	0	23100	172575	27540	434687
7	293161	2387	28710	149916	6426	106200	0	135405	21870	293161
8	222398	15004	54230	738048	3060	276120	47124	0	19035	738048
9	252725	16027	56144	772644	5814	288864	49896	124785	0	772644

From Table 15, it is observed that the percentage of infected
individuals in the Eastern Region is 22.35%, while the mortality is at 2.7%.

From Table 16, it is observed that *the weighted c-center* is vertex 3, which corresponds to the municipality of *Gradsko.*

4. The social-economic and health advantages of c-centers of weight

In this paper, North Macedonia is divided into eight regions, which correspond to the developmental planning regions defined by the Assembly of the Republic of North Macedonia. Consequently, we identified eight weighted c-centers, which are: Skopje, Kumanovo, Bogovinje, Mogila, Valandovo, Debarca, Karbinci, and Gradsko.

The advantages of establishing eight infectious disease centers in North Macedonia are:

- each patient could, on average, reach their regional c-center more quickly.
- Faster and more efficient treatment.
- The number of patients seeking medical help would increase.
- Mortality rates would decrease.
- The infectious disease clinic in Skopje would be relieved from the pressure of overload.
- On average, the cost of expenses for each patient would decrease.
- It would give an impetus to the economic development of the weighted c-center, etc.

5. Conclusions

After providing theoretical support for our objective, we successfully achieved several significant results:

- The weighted c-centers in the eight regions of North Macedonia are: Skopje, Kumanovo, Bogovinje, Mogila, Valandovo, Debarca, Karbinci, and Gradsko.
- Several socio-economic arguments were presented for these c-centers;
- Various health-related arguments were given, with the most convincing being the lower mortality rate in the Skopje region compared to the mortality rates in other regions.

We hope that with this paper, we have managed to address an urgent healthcare issue by providing a more efficient approach for handling the pandemic in North Macedonia.

REFERENCES

[1] Kedhi Vasillaq. Chapter 7 “Knowledge about graphs” , Chapter 8 “Shortest path problems” in Operational research (Kerkimi operacional), DitaPrint, Tirana, ISBN 978-99928-229-11-3, 2017, pp.225-289

[2] Robin J. Wilson ,“Chapter 1, Introduction” in Introduction to Graph Theory, Fourth edition, LONGMAN, Reprinted 1998, pp.1-8

[3] Azir Jusufi, Kristaq Filipi,”Chapter 11, Elements of graph theory” in Discrete Mathematics and applications (Matematike Diskrete dhe aplikime), UBT Pristina, ISBN: 978-9951-550-52-9, 2022, pp.299-330.

[4] Kenneth H. Rosen, “Chapter 10, Graphs” in *Discrete Mathematics and its Applications,* Eighth Edition, The McGraw-Hill Companies, 2019, pp.673-780

[5] Thoma Mitre, Alma Spaho,”Part Two, Graphs and Networks” in Applied Mathematics (Matematika e Zbatuar), Botime Pegi,Tirana, ISBN:978-9928-233-01-1, 2016, pp. 213-320

[6] Hysen Binjaku, “Chapter 7. Network optimization” in Mathematics exercises (Ushtrime te Matematikes), Infobotues,Tirana, ISBN 978-99956-830-2-3, 2010, pp.143-206

[7] Diellza Berisha, Bukurie Imeri-Jusufi, Mirlinda Reqica, Azir Jusufi, *Social-economic advantages of c-centres and m-centres with weight in Kosovo*, Innovative Systems Design and Engineering, Vol 12, No.5, pp.21-29, 2022. DOI: 10.7176/ISDE/12-5-04

[8] Bukurie Imeri Jusufi, Teuta Jusufi-Zenku, Azir Jusufi*, Social -Economic Advantages Of Weighted C-Centers And M-Centers In North Macedonia,* International Journal of Progressive Sciences and Technologies Vol 35, No 1, pp. 86-97, 2022. DOI: 10.52155/ijpsat.v35.1.4677.