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Multi-Modal Routing using MPNSGA-II Algorithm Considering Covid-19 Protocols: A Case Study in Tehran

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ABSTRACT

Nowadays, the utilization of urban public transportation has become a routine for people living in large cities. It is necessary to use multi-modal along the path to move individuals from one point to another. With the initiation of the Covid-19 pandemic, megalopolis public transportation became an effective place for transmitting the virus. Hence, this study used a multi-modal route according to health protocols. Tehran is home to the largest transportation network in Iran, so its public transportation network has been used in this paper. Subway, bus, taxi, and pedestrianism are 4 investigated structures. Also, the multi-modal routing problem is solved as multi-objective and by using the NSGA-II algorithm. The effective goals in choosing an optimal path according to the health protocols of Covid-19 include traffic, path length, traveler's contact with surfaces, air conditioning, and social distance. A basic Genetic algorithm was used to verify the selected path by the NSGA-II algorithm and a new algorithm that has been improved base on NSGA-II in this paper which has been named MPNSGA-II (Multi-Parent NSGA-II): Five target functions were evaluated one by one using the Genetic algorithm, and their results were compared with those of the NSGA-II, and MPNSGA-II algorithms. Based on real data obtained from public transportation in Tehran, the proposed routes are rational and acceptable. GA could solve in 4.4 seconds and NSGA-II and MPNSGA-II in about 10 seconds. MPNSGA-II generally can reach a better amount of variance, for example: The distance between people objective function for MPNSGA-II is 27.34, for NSGA-II is 62.21 and for GA is 48.73.

KEYWORDS

Multi-modal Routing,
Covid-19,
NSGA-II,
MPNSGA-II,
Public Transportation,
Optimization,
Urban Transportation Network

1. Introduction

The World Health Organization (WHO) announced the Covid-19 pandemic on March 11, 2020 (W. Health Organization, "WHO," Word Health Organization, 2019., n.d.). It influenced all the societies like an enormous tsunami and changed the daily life of people all around the world. Urban public transportation has been one of the parts significantly influenced by this pandemic (Shelat et al., 2022), (Simić et al., 2022), (Przybylowski et al., 2021), (Kim, 2022). As a result of the outbreak of the Coronavirus, for example, Hong Kong has seen a 40% decrease in public transportation usage (Kwok et al., 2020). Urban transportation significantly impacts air pollution, traffic, virus propagation, etc. (Simić et al., 2022), (Abdullah et al.,

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2021), (Mogaji et al., 2022). Therefore, in the Covid-19 pandemic, special planning and management of urban transportation are required to control the virus's spread.

Metropolises employ a variety of transportation methods to get commuters around on a daily basis (Faroqi & saadi Mesgari, 2016). Citizens decide their path regarding various criteria, which are different for each individual based on their condition and interests(Litman, 2017). For example, starting the Covid-19 pandemic, the path with less congestion is preferred (Brinchi et al., 2020). Urban transportation networks usually have subways, buses, taxis, and pedestrian infrastructures. The subway modal has more congestion, less distance, and no traffic, while the bicycle modal is less in touch with other individuals. With the outbreak of the Coronavirus, citizens prefer their private vehicles, which causes an increase in traffic, fuel consumption, and air pollution (Simić et al., 2022). As a result, if commuters are provided with the option to choose a path according to Covid-19 health protocols, public transportation can be managed properly, and citizen health can be improved.

Multi-modal routing problem is from complex problems and has extended response space (Litman, 2017). With the increase in the network mass, complication develops. Multi-modal routing problem is a multi-objective problem considering its various goals, which are not coextensive (Pahlavani & Ghaderi, 2017). Multi-modal routing problem is similar to optimization problems and is not solvable by accurate methods (Deb, 2014). There are several optimal responses to multi-objective problems, not just one. The meta-heuristic algorithms are efficient for optimizing such complicated problems (Faroqi & saadi Mesgari, 2016). The Genetic algorithm(Whitley, 1994) and its upgraded version, the NSGA-II algorithm (Deb et al., 2002), are the most basic meta-heuristic algorithms. These algorithms have been efficient in solving routing problems (Yu & Lu, 2012). The Genetic and NSGA-II algorithms are usable in solving continuous and discrete problems. As a result, the Genetic and NSGA-II algorithms are very appropriate for dealing with the multi-modal routing problem because it is discrete (El Hassani et al., 2015).

In this study, multi-modal routing has subways, buses, taxis, and walking models. It is also in multi-objective form, and goals such as path length, air conditioning, the need for touching surfaces in the modal, congestion, and traffic are considered. Additionally, the time limitation of the traveler's stay in modals of subways, taxis, and buses is employed as a constraint. The NSGA-II and MPNSGA-II algorithm is used to solve this problem in the transportation network of the Tehran metropolis. Utilizing the Tehran transportation network data and the Genetic algorithm, the single-objective problem (path length) is used to compare the obtained path with Covid-19 health protocols.

In this study, we have two innovations, one is in the methodology section and the other is in the application section. In this study, the NSGA-II algorithm has been upgraded to the MPNSGA-II algorithm. In NSGA-II, a combination of two parents is used, while in the MPNSGA-II algorithm, a combination of 5 parents is used. The problem of multi-modal routing by considering the objective functions according to the health protocols of Covid-19 has not been solved until now, which has been solved in this study by considering Length, Distance between people, Traffic, Touching the Surfaces, and Air conditioning objective functions.

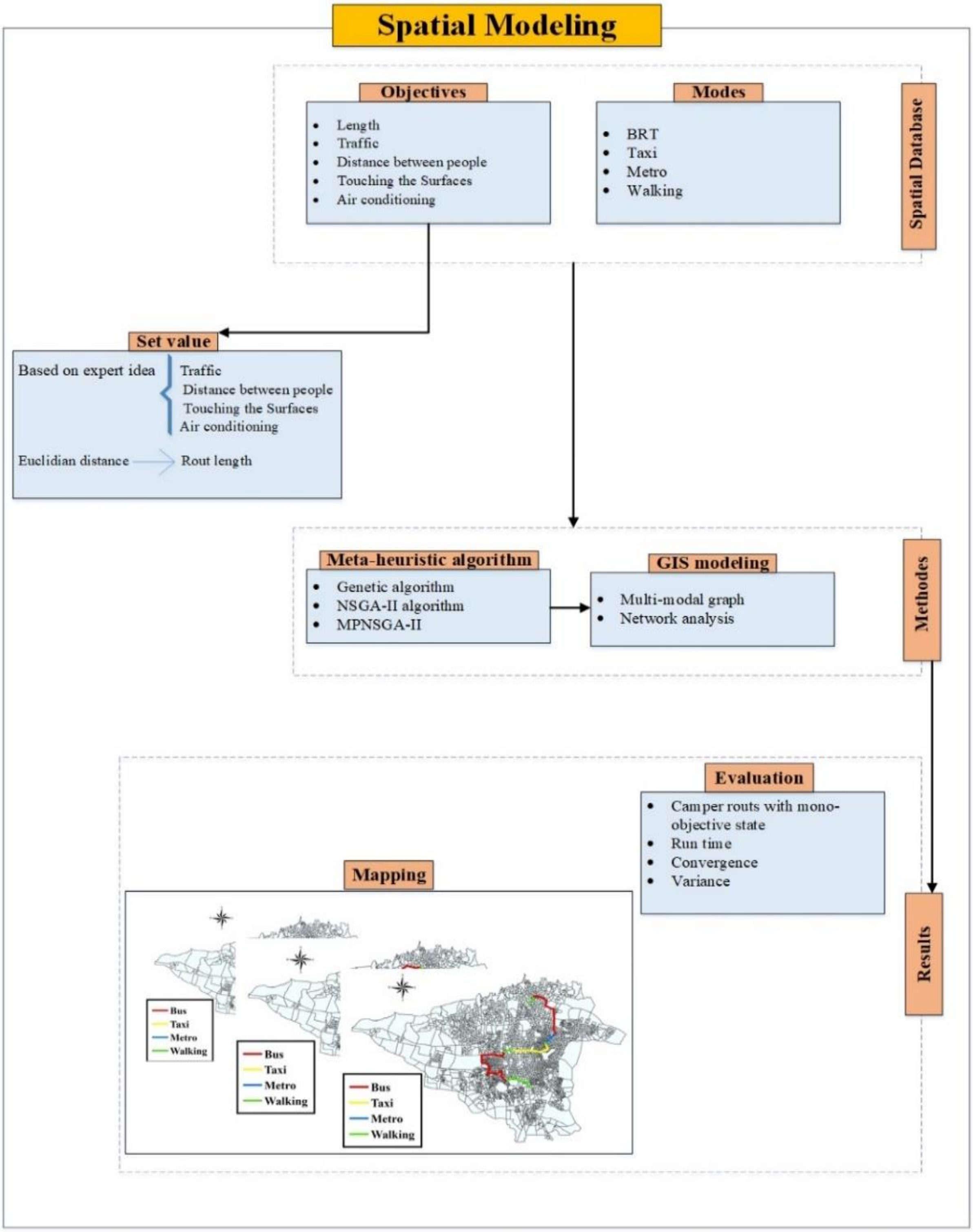


Figure 1. Steps of research

2. Literature Review

The routing problem goes back to the time when Mr. Hamilton presented the traveling salesman problem (TSP) for the first time(Gutin & Yeo, 2001). With the expansion of cities, transportation networks becoming more complicated, and the creation of multi-modal transportation networks, the need for using a path with a combination of some modal emerged (Pajor, 2009). The urban transportation network was, therefore, subject to much research in search of an integrated multi-modal path. The multimodal transportation network and routing were first investigated as a single-objective (typically path length), while citizens have multiple non-coextensive goals for choosing a path. It led to the multi-modal routing problem being analyzed as a multi-objective optimization problem(Caramia & Dell'Olmo, 2020).

Stochastic approaches are suitable for this problem because the routing problem is inherently an optimization problem. Gharib et al. solved the TSP problem by using the Genetic algorithm (Gharib et al., 2015). Deng et al. solved the multi-modal routing problem through the Genetic algorithm(Deng & Hu, 2011). Pahlavani et al. solved the multi-modal routing problem by considering the objectives of traveling time, cost, and modal changes along the path using the NSGA-II algorithm. The multi-modal network of the previous study is a part of the Tehran transportation network with subways, buses, taxis, and walking models. Pahlavani et al. have prioritized the obtained set of results by using the TOPSIS approach. The results show that the NSGA-II algorithm is suitable for this problem (Pahlavani & Ghaderi, 2017).

After the Covid-19 pandemic outbreak, researchers began investigating and studying different discussions on this issue. In their paper, Patlins et al. provided some of the government's actions for reducing the Covid-19 impacts. They have categorized these actions into three groups: travelers, organizations, and carriers. They also provided the most prevalent mistakes during the usage of public transportation. Then have proposed some recommendations for reducing the negative effects of Covid-19 (Patlins, 2021). Gutiérrez et al. investigated the consequences of the Covid-19 pandemic on public transportation (Gutiérrez et al., 2020). With the help of questionnaires among citizens of Gdansk city, Przybylowski et al. were able to gather some data about factors that contributed significantly to the citizens' feeling of safety using public transportation during the Covid-19 pandemic. Additionally, Charoennapharat et al. investigated the effective factors of multi-modal transportation during the Covid-19 pandemic in Thailand (Charoennapharat & Chaopaisarn, 2022). Abreu et al. presented a qualitative analysis of changes in the New York

transportation system during the Covid-19 pandemic. They also provided suggestions for the future of public transportation management (Abreu & Conway, 2021). Previously, the focus was on the effects of Covid-19 on public transportation and recommendations for future pandemics, but no practical approach to enhancing public transportation utilization by travelers was presented in the literature.

The research was conducted to examine precautionary measures and the control of COVID-19 by the government and everybody, as well as the impact of COVID-19 on public transportation. In other words, they suggest public actions. In this study, we consider a state in which the situation is immutable, and we should accept it and provide an individual practical solution. Our solution is that the commuter uses a path in which the Covid-19 infection danger is at the minimum. Several precautionary and control solutions for Corona are not practical or need time, cost, and public efforts from people and governments. In this situation, the practical solution is to find a multi-modal path with the least danger of infection for the commuter. There has not yet been a declaration by WHO that Covid-19 is over (Ann Junio, 2022), and even after that, we may witness another epidemic. Preparations for dealing with this pandemic and virus infection in the future are therefore critical. The main innovation of this study is presenting an optimal path for commuters with the minimum risk of Coronavirus infection.

3. Materials and Methods

3.1. Methodology

This study has been performed in 3 steps in accordance to figure 1. The spatial database was designed in the first stage. The database includes five objective functions and 4 transportation models. The public transportation of the Tehran metropolis has been utilized. In the second step, the multi-modal problem is analyzed using a multi-modal graph, network analysis, and GIS modeling, and the problem is solved using the NSGA-II and MPNSGA-II algorithms. The basic Genetic algorithm is used for the evaluation of results. Finally, the results will be evaluated based on run convergence, algorithm run time, and comparison of the NSGA-II path with that obtained from the Genetic algorithm. The optimized path is visualized for more understanding.

3.2. Study Area

The studied region is the Tehran metropolis. Tehran is the capital and the most populous city of Iran. Tehran is 751 Km2 and is located from 51° 6’ to 51° 38’ East lengths and 35° 34’ to 35° 51’ north width. Tehran population is larger than 8,693,706 (Amar, n.d.).

Therefore, Tehran is a congestive city, and this population needs to use public transportation. Tehran poses the most powerful and complicated transportation network in Iran. During the Covid-19 pandemic, public transportation in Tehran became a challenging issue. Additionally, Tehran had the most susceptibility at the beginning of the Covid-19 pandemic. At this time, because health protocols in subways, buses, etc., were hard to regard, the usage of private vehicles in Tehran increased significantly. It caused an increase in traffic and other relevant problems. Figure 2 shows the plan of the studied area.

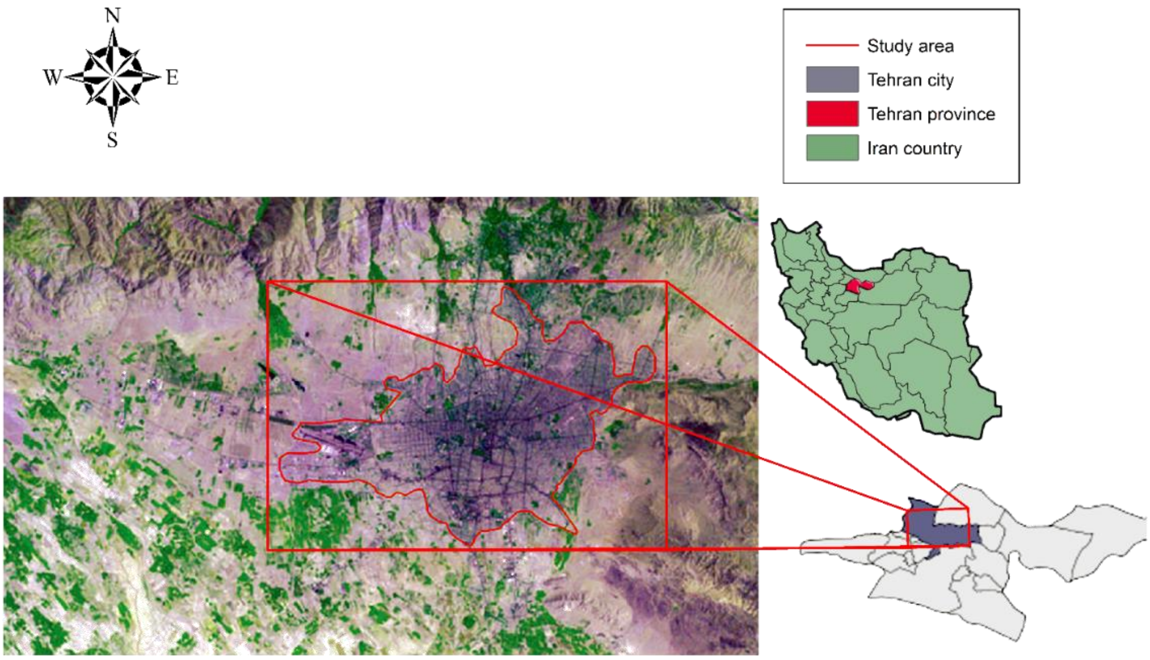


Figure 2. The study area

3.3. Multi-modal routing

The multi-modal network is a network in which different structures of travel, such as walking, subway, taxi, etc., are employed as a combination for network analysis (Faroqi & Mesgari, 2016). Generally, it is difficult to model transportation systems, especially when the number of travel structures increases. Multi-modal transportation system (MTS) is a combination of all traveling states and transportation systems, which operates through different systems. It means that commuters simultaneously use a set of transportation approaches to reach their destination (Pajor, 2009).

Multi-modal network modeling uses graphs, label matrices, and vicinity matrices. Nodes represent stations, and lines show the connection between them. The Vicinity matrix is defined as isometric to the network and contains both 0 and 1 numbers. It shows the connection or disconnection between stations (Faroqi & saadi Mesgari, 2016). Entries of the principal diagonal of the vicinity matrix are zero because the path does not have any turn. The label matrix is defined as isometric to the network, which determines the modal of each line. In other words, labels are being applied to lines. In figure 3, a sample of the vicinity and label matrix has been shown. In figure 3 (a), the number 1 shows a line between two nodes, and 0 indicates that there is no line between two nodes. In figure 3 (b), each number represents the type of the considered structure between two nodes (stations). For example, in the second entry, number 1 defines the type of structure between stations number 1 and 2.

$$\begin{bmatrix} 0 & 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 & 1 & 0 \end{bmatrix} \qquad \begin{bmatrix} 0 & 1 & 2 & 0 & 1 & 3 \\ 1 & 0 & 1 & 4 & 3 & 1 \\ 2 & 1 & 0 & 0 & 4 & 1 \\ 0 & 4 & 0 & 0 & 2 & 0 \\ 1 & 3 & 4 & 2 & 0 & 1 \\ 3 & 1 & 1 & 0 & 1 & 0 \end{bmatrix}$$

(a) (b)

Figure 3. Multi-modal matrix (a) Adjacency matrix, (b) Label matrix

In Figure 4, a sample of a multi-modal route has been shown. In this route, 4structures of taxis, subways, buses, and walking exist. A walking modal was used for replacement between models. It consists of nine lines and ten nodes.

In public transportation in Tehran, buses, subways, taxis, and walking modals are the most important structures. For this reason, this study investigated 4modals. In the studied network, 408 stations were used, according to Table 1. A walking modal is defined as a modal without a station and with the objective of replacement between models.

Table 1. The number of stations in each mode

Mode	Vertex	Edge
Bus	235	237
Subway	90	93
Taxi	83	82
Total	408	412

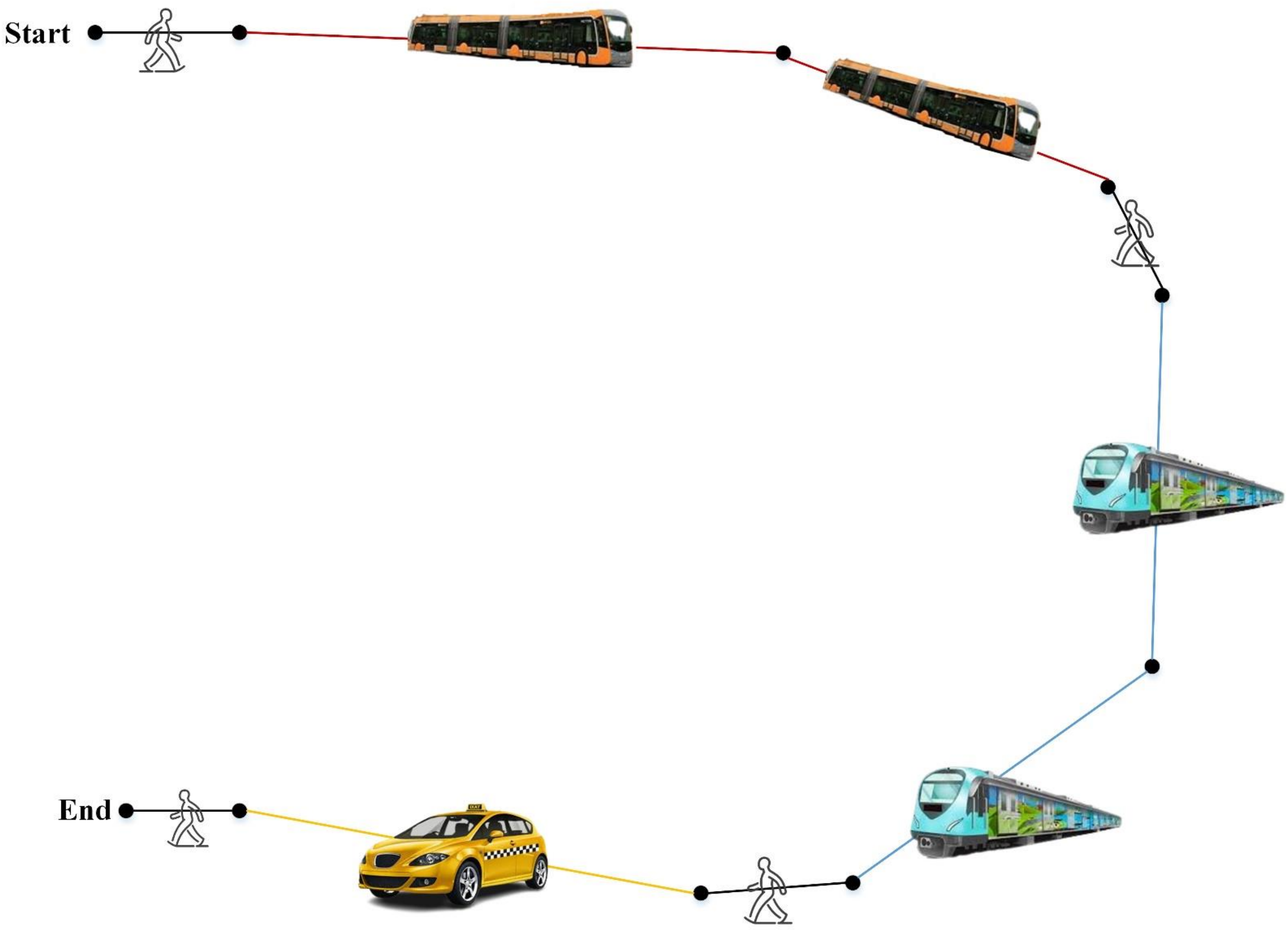


Figure 4. An example of a multi-modal rout

Due to its powerful functions in managing spatial data, GIS is involved in many areas that include spatial data, such as transportation systems. GIS-T is used for presenting GIS functions in transportation. Besides common GIS tools, such as buffers and overlapping tools, GIST is well-suited for solving transportation issues. The main capabilities are analyzing the shortest path, network flow model, and urban transportation (Chen et al., 2011). Also, network analysis in GIS is one of the powerful approaches for multi-modal route problem modeling, which has been used in this study.

3.4. Genetic and NSGA-II Algorithm

The Genetic algorithm was presented by Holland et al., 1988 (Goldberg & Holland, 1988). It is based on Darvin's evolution theory. The Genetic algorithm is based on concepts of genes, chromosomes, parents, and children. Each chromosome consists of a set of genes. It means each chromosome is an answer to the problem, and each gene is a part of the solution. A new child is created when at least one parent exists. Cross-over operators and mutation lead to the creation of the next generation. The cross-over operator causes the utilization of answers, and the mutation operator causes the finding of supplementary responses. The balance should be established proportionally between the two operators of mutation and cross-over. The Genetic algorithm is a single-objective optimization algorithm and can be used for problems with discrete and continuous space.

Deb et al., 2002, presented the non-Dominated Sorting Genetic Algorithm (NSGA-II) as multi-objective. The NSGA-II involved sorting responses, obtaining each set of responses, and applying the congestion distance to each set of responses (Tomoiagă et al., 2013).

A random selection method is also used to select parents, just like the Genetic algorithm. More optimized chromosomes have a greater chance of being chosen as parents, yet all chromosomes have the chance to be selected as parents. The revolving wheel is the most common approach for random selection in algorithms. Based on the chromosome revolving wheel, which has a higher optimization, a larger sector is assigned and has a higher chance of being chosen (Hamdani et al., 2007).

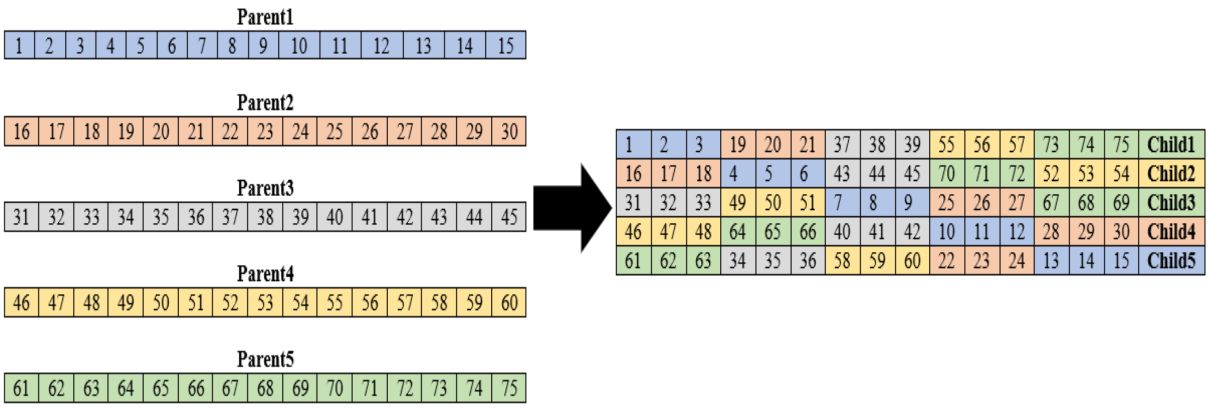


Figure 5. Multi-Parent cross-over in MPNSGA-II algorithm (five parent)

3.5. Multi-parent non-dominated sorting genetic algorithm (MPNSGA_II)

The NSGA-II basic algorithm is a powerful algorithm that has been used in many pieces of research and has been able to perform well; But the problem for the genetic algorithm and NSGA-II is the issue of weakness in exploitation, which by its crossover operator leads to getting stuck in the local optimum and around a solution. In the simple crossover, only the combination of two parents is used (Figure 5), which leads to falling into the local minimum. Now, in this study, we want to use several parents instead of two parents, which increases the diversity in the answers (children). This solution solves the problem of genetic algorithm exploitation and exploitation. In this study, five parents were used instead of cross-over two parents. The cross-over of five parents and children is shown in Figure 5.

4. Modeling

4.1. Problem Modeling in the Algorithm Format

The multi-modal problem in this research has objectives of path length, individual distance (empty space), air conditioning, surface contact, and traffic. Additionally, the allowable stay time in each modal for the NSGA-II algorithm is a maximum of 15 min and is added to the problem as a constraint. A multimodal network incorporates subways, buses, pedestrians, and taxis. We should first determine the response definition method for modeling the considered problem in the NSGA-II and Genetic algorithms.

A multi-modal path is created from station sequence and modal type. In NSGA-II and Genetic algorithms, every chromosome represents an answer (route). Genes in a multi-modal problem include station vertices and the structure type. In this study, each odd gene shows a station, and even genes show the structure type between its next and previous genes. Figure 6 indicates two chromosomes with similar origins and destinations.

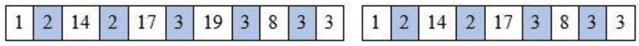


Figure 6. Indication of two chromosomes of two multi-modal routes with similar origin and destination. The values of even genes are related to the creation of the connection line between the two next and previous stations. Even genes show the station number.

In this study, a single-point cross-over is used for cross-over implication. Also, a substitution-mutation operator is used for mutation implication. The modeling method is similar in both Genetic and NSGA-II algorithms. A comparison between a path following all health protocols of Covid-19 and one that only considers one is made using five different target functions in different runs of the Genetic algorithm.

4.2. Objective Function

Everyone requires different criteria for selecting a route. Regarding the Covid-19 pandemic, many people considered a safer route in terms of Coronavirus infection as a priority. It has not been considered in previous research. In other words, the innovation of this study is finding a route with a minimum risk of Coronavirus spread. Therefore, regarding (Charoennapharat & Chaopaisarn, 2022), (Rashedi & Al, 2020), (Anand et al., 2021), (Wang et al., 2022), (Baniasad et al., 2021) references, in public transportation, individual distance (empty space), air conditioning, surface contact, and staying time in each structure are effective in virus transmission. In this study, the objectives are path length, individual distance (space), air conditioning, surface contact, and traffic. As a constraint in the NSGA-II algorithm, durations longer than 15 minutes are also added to each structure. An optimal route has a shorter length pat, lower traffic, and less surface contact. Additionally, air conditioning and space between individuals are considerable. The path length is calculated independently from the modal type and by using Eq. (1) or the Yukledin Distance equation.

$$D_{i,j} = \sqrt{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2} \quad (1)$$

Four objective functions, including individual distance (space), air conditioning, surface contact, and traffic, are prioritized according to professional opinion. Given that the optimization problem is solved by goal minimization, the goal function with the highest priority is 1, while the goal function with the lowest priority is 4. According to the Table 2, the traffic function in the subway modal has the lowest value, thus a higher priority. Of the other 3 goal functions, the subway modal has the lowest priority. Also, the walking modal in three functions of air conditioning, individual distance, and surface contact is at the highest priority. In other words, the walking modal has the lowest contact surface and the largest air conditioning.

Table 2. Goal prioritization based on the modal type

Objective Mode	Traffic	Touching the Surfaces	Air conditioning	Distance between people
Bus	3	3	2	3
Metro	1	4	4	4
Taxi	4	2	2	2
Walking	**2**	**1**	**1**	**1**

5. Results

The Genetic algorithm runs 24 times for each of the 5 existing goals functions to compare the multi- and single-objective states of the problem. In order to understand algorithm behavior, two states of indulgence and balance have been incorporated in the adjustment of cross-over and mutation parameters.

The values of the goal function in 24 runs have been shown in table 4 according to the adjusted parameters in table 3 for Genetic and NSGA-II algorithms. A Genetic algorithm runs 24 times on five different goal functions, one by one.

Table 3. Values of adjusted parameters based on trial-and-error method for the Genetic, NSGA-II, and MPNSGA-II algorithms

Run No.	Max Number of Iterations	Number of Chromosome	Cross Over rate	*Mutation Rate*
1	50	25	0.1	*0.9*
2	100	25	0.1	*0.9*
3	50	25	0.4	*0.6*
4	100	25	0.4	*0.6*
5	50	25	0.1	*0.6*
6	50	25	0.4	*0.9*
7	50	25	0.6	*0.1*
8	50	25	0.9	*0.4*
9	100	25	0.1	*0.6*
10	100	25	0.4	*0.9*
11	100	25	0.6	*0.1*
12	100	25	0.9	*0.4*
13	50	50	0.1	*0.9*
14	100	50	0.1	*0.9*
15	50	50	0.4	*0.6*
16	100	50	0.4	*0.6*
17	50	50	0.1	*0.6*
18	50	50	0.4	*0.9*
19	50	50	0.6	*0.1*
20	50	50	0.9	*0.4*
21	100	50	0.1	*0.6*
22	100	50	0.4	*0.9*
23	100	50	0.6	*0.1*
24	100	50	0.9	*0.4*

According to Table 4, both Genetic and NSGA-II algorithms have obtained better results in the state that cross-over and mutation rates are indulgently 0.1 and 0.9. Genetic algorithms have generally obtained better goal functions; because when the optimization problem is single-objective, the algorithm is only optimizing one goal, while in the multi-objective scenario, a balance should be established between multiple goals

Table 4. The values of the goal function in 24 runs for all algorithms

Algorithm	Run No.	Length Objective Function	Distance between People Objective function	Traffic objective function	Touching the Surfaces objective function	Air conditioning objective function
	1	10	31	22	18	31
	2	12	28	27	15	44
	3	21	41	36	24	41
	4	26	47	41	33	56
	5	23	33	28	21	38
	6	28	37	35	25	44
	7	18	31	32	32	41
	8	19	34	30	41	39
	9	21	44	47	37	48
	10	17	48	39	29	57
	11	13	47	44	17	59
Genetic	12	12	35	29	25	60
	13	21	42	37	31	55
	14	29	47	31	38	47
	15	15	39	40	40	43
	16	18	51	46	32	49
	17	22	49	51	24	52
	18	17	46	39	27	35
	19	14	35	36	36	33
	20	18	41	37	41	39
	21	25	30	28	39	41
	22	21	33	33	28	47
	23	12	34	44	36	51
	24	13	34	41	19	51
	1	25	38	63	22	36
	2	47	34	110	36	71
	3	68	45	156	31	58
	4	63	48	159	42.5	64
	5	44	44	100	44	41
	6	47	44	112	41	44
	7	49	48	98	35	44
	8	72	52	99	38	49
	9	56	58	82	29	52
	10	57	59	121	30	50
	11	38	39	128	31	61
NSGA-II	12	42	41	133	31	59
	13	45	37	117	44	58
	14	55	61	121	45	57
	15	51	59	125	41	57
	16	61	59	142	39	71
	17	66	51	151	25	70
	18	59	47	144	27	69
	19	48	44	134	29	68
	20	47	41	126	33	60
	21	47	38	121	38	56
	22	70	42	132	40	49
	23	71	47	149	41	68
	24	68	51	155	39	71
MPNSGA-	1	14	42	26	21	34

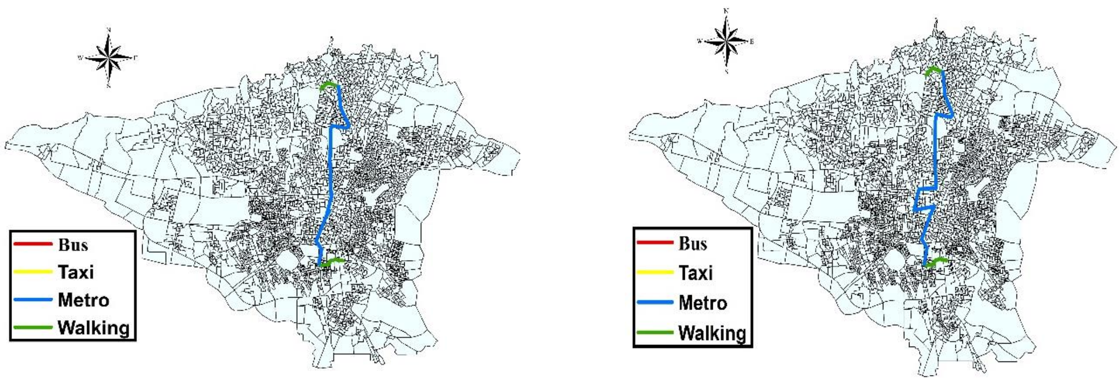
II	2	17	39	19	22	33
	3	11	28	22	16	29
	4	15	26	28	12	31
	5	22	35	33	27	37
	6	26	37	31	33	36
	7	27	36	35	31	32
	8	20	41	33	38	34
	9	31	39	42	29	39
	10	27	42	48	25	42
	11	18	41	55	28	47
	12	13	37	51	25	46
	13	21	32	47	32	44
	14	32	48	63	33	49
	15	29	42	54	33	52
	16	38	36	47	37	48
	17	36	34	43	38	41
	18	32	33	48	32	39
	19	27	44	54	26	40
	20	18	41	44	29	48
	21	24	38	45	32	53
	22	24	43	58	30	56
	23	37	40	69	38	50
	24	39	45	71	35	57

Algorithms have been implemented in 24 parameter setting modes. In each run, values are obtained for each objective function. A statistical test of variance has been used to show the deviation of the objective function values. In Table 5, you can see the variance values of each objective function in each algorithm. Based on Table 5, MPNSGA-II can reach better variance amounts in general.

Table 5. The values of Variance the amount of Table 4

	Length Objective Function	**Distance Between People Objective Function**	**Traffic Objective Function**	**Touching the Surfaces Objective Function**	**Air conditioning Objective Function**
GA	*28.43*	48.73	52.07	65.04	66.8
NSGA-II	141.82	62.21	579.64	43.9	106.59
MPNSGA-II	68.16	27.34	196.25	45.15	67.46

Figure 7 shows some of the obtained routes from different states of running the Genetic algorithm for 5 objective functions in table 3 separately. In Genetic algorithms, staying time limits are not applied for each modal. Figure 7 indicates that the Genetic algorithm has been able to find the optimal paths in various runs properly.



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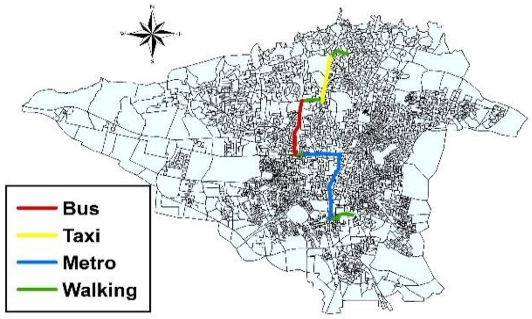

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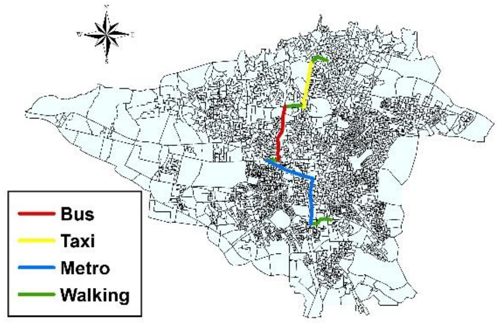

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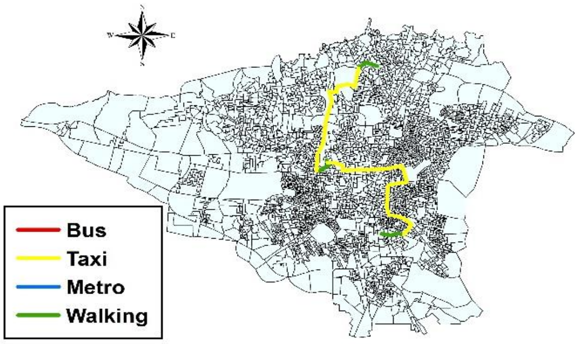
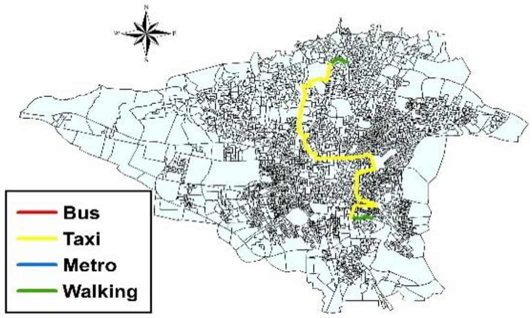
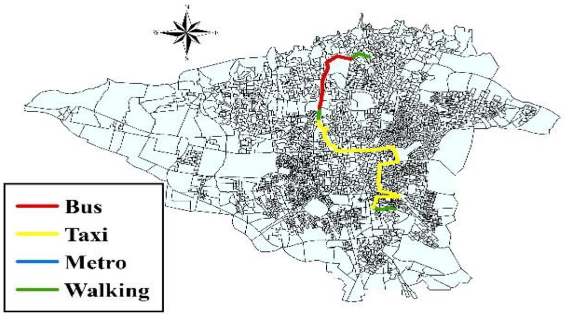


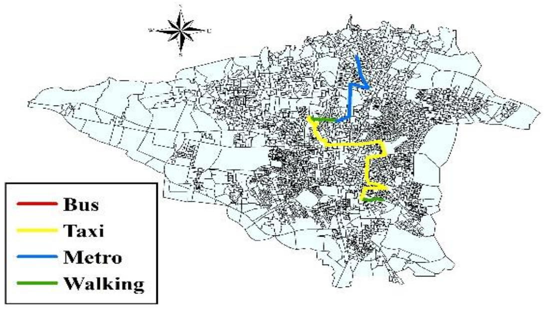
b1



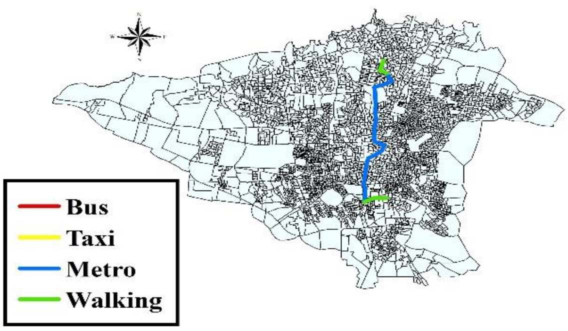
b2



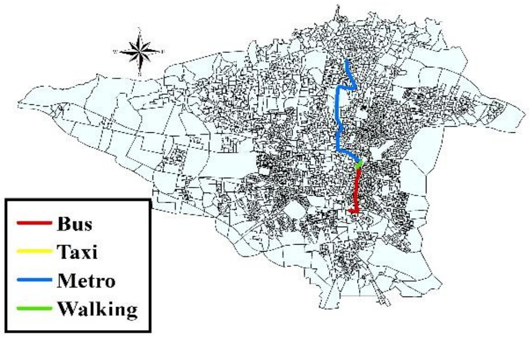
b3



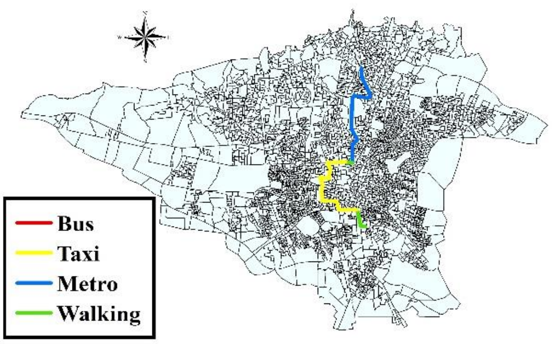
b4



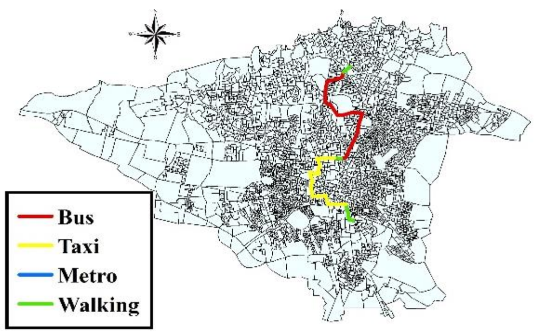
c1



c2



c3



c4

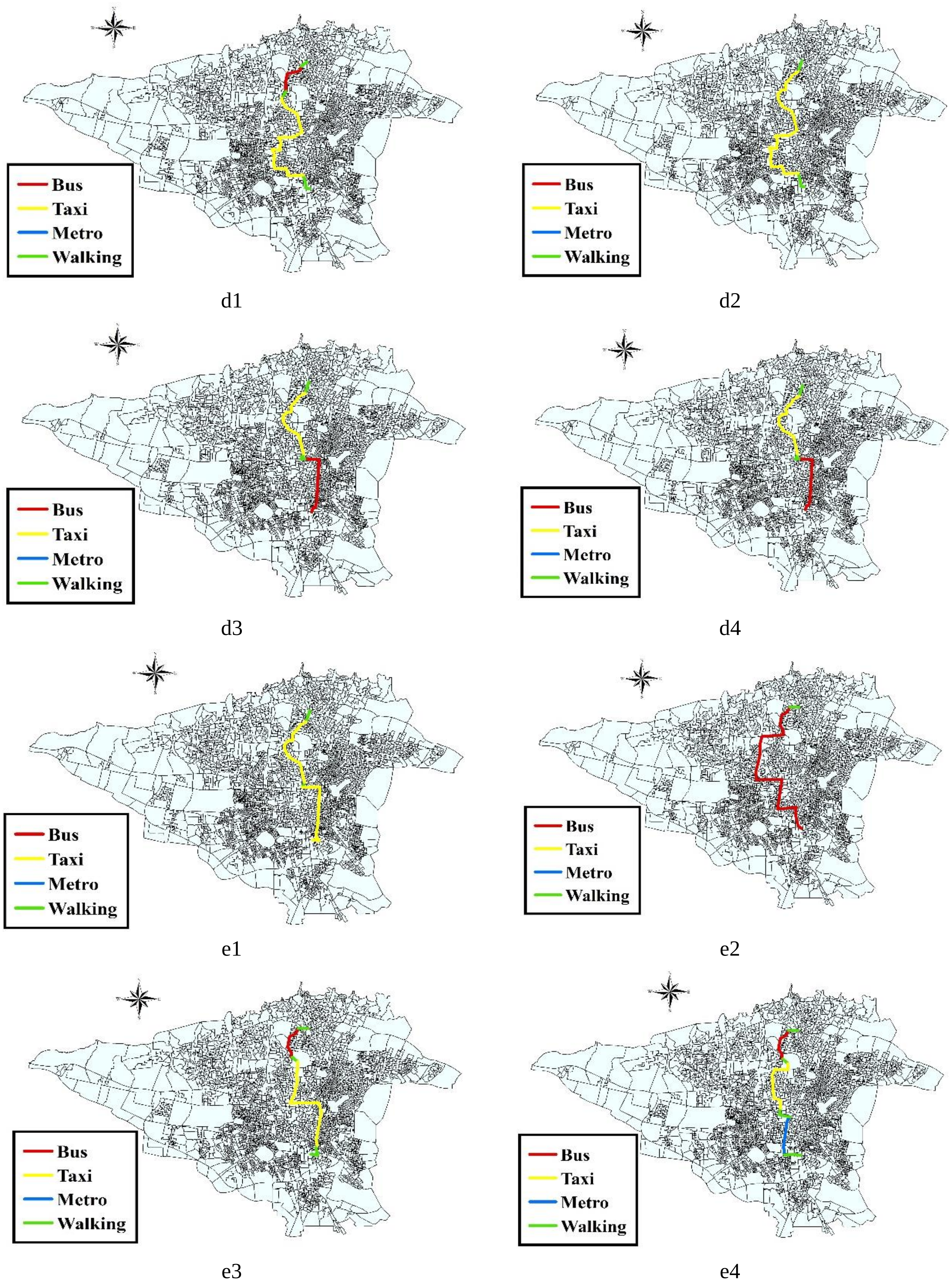


Figure 7. The obtained paths by the Genetic algorithm (a1), (a2), (a3), (a4): Length (b1), (b2), (b3), (b4): Distance between people (c1), (c2), (c3), (c4): Traffic (d1), (d2), (d3), (d4): Touching the Surfaces (e1), (e2), (e3), (e4): Air conditioning,

,

Figure 8 shows the multi-modal routes obtained from the NSGA-II algorithm in four runs according to Table 3. In the NSGA-II algorithm, substitution between models has been conducted by using a walking modal. Also, a time limit of 20 minutes for staying in each modal to prevent Coronavirus infection is implicated. Based on Figure 8, the obtained routes have a longer path length than the Genetic algorithm results. Thus, the algorithm has been able to find routes proportional to objectives. Figure 8 shows that the modal is substituted after passing through some stations due to time constraints in each modal.

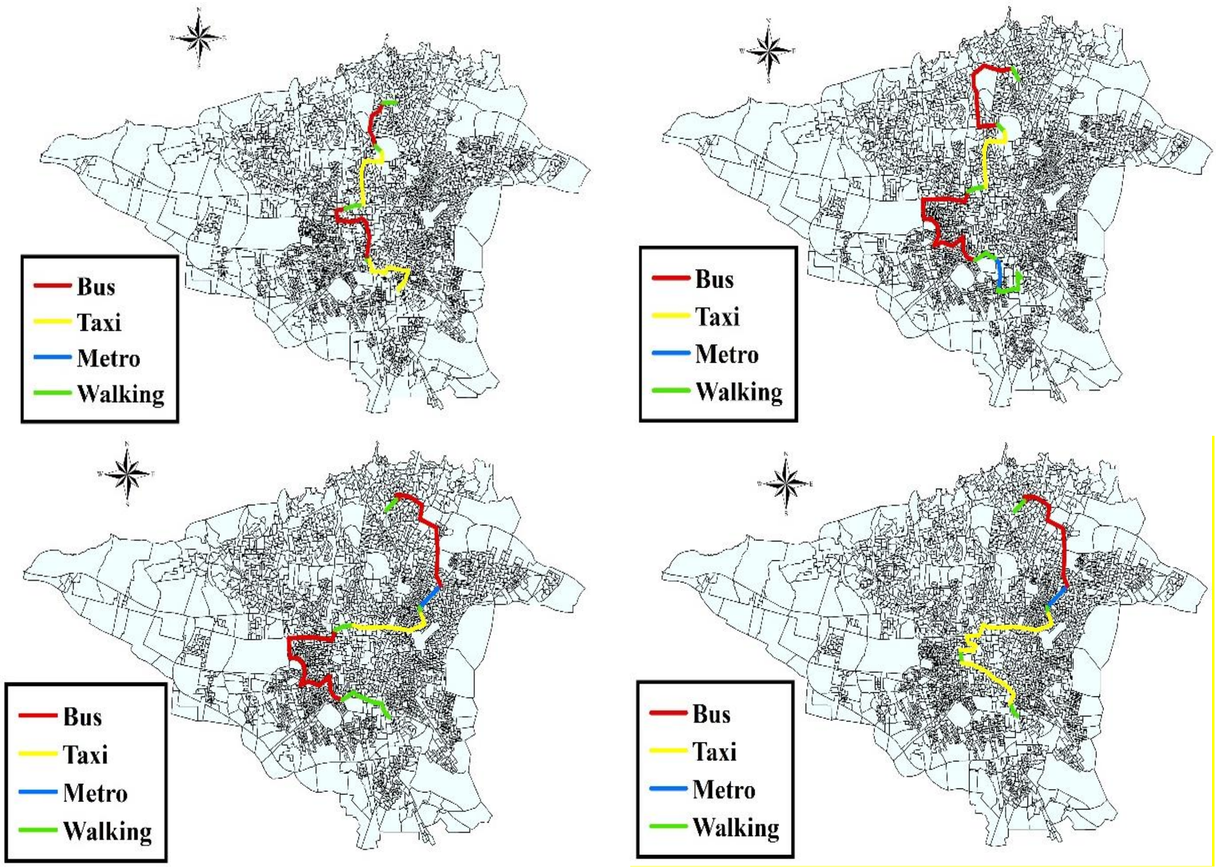


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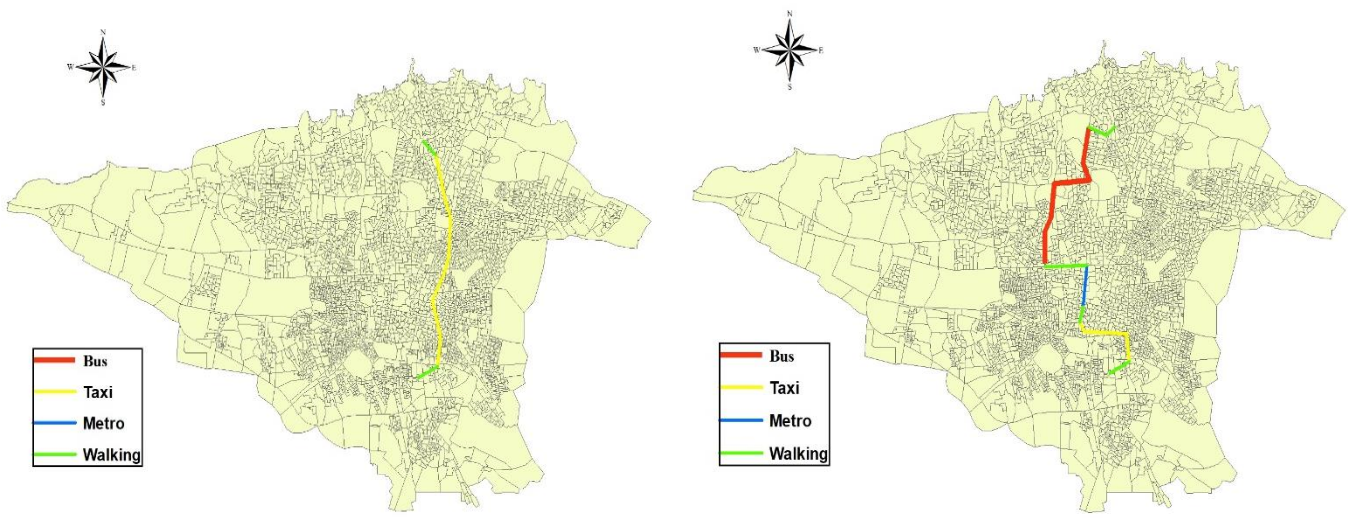
Figure 8. The obtained routes by the NSGA-II algorithm

Figure 9 shows the paths found by the MPNSGA-II algorithm. Like the NSGA-II algorithm, the walking mode is used to replace modal; Also, a constraint of 20 minutes has been applied for each mode. Comparing Figure 8 and Figure 9 shows that the improved MPNSGA-II algorithm can find better paths.



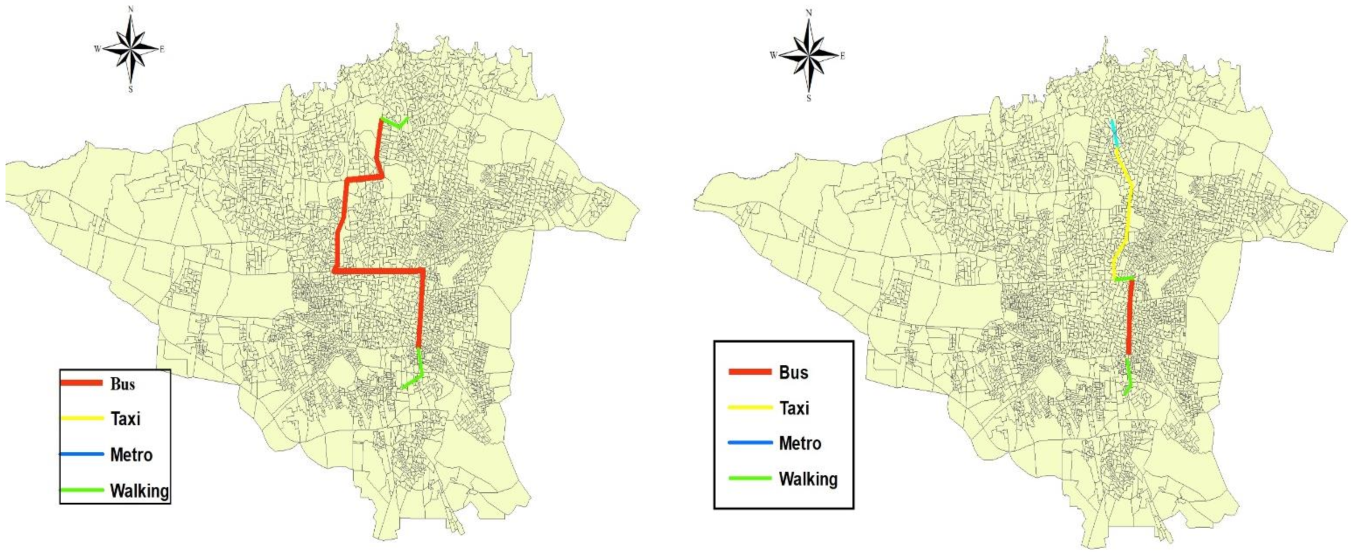


Figure 9. The obtained routes by the MPNSGA-II algorithm

The run time of both algorithms is shown in Table 6. The duration of the Genetic algorithm is related to the average run time of five objective functions in the first run. Obviously, in different runs of every algorithm, a similar duration is required.

Table 6. Each algorithm run time in 24 runs according to table 3

Run No.	GA (Seconds)	NSGA-II (Seconds)	MPNSGA-II
1	2/5	8	8.4
2	2/8	8/9	8.2
3	2/8	8/3	8.3
4	2/6	8/48	8.4
5	3.2	9.2	8.8
6	3.3	9.1	8.9
7	3.1	9.1	8.8
8	3.4	9.4	9
9	4.4	10.1	10.4
10	4.3	9.9	10.8
11	4.4	10.5	10.2
12	4.1	10.6	10.3
13	4.9	10.3	10
14	4.8	10.4	10.8
15	4.7	10.2	10.5
16	4.8	10.6	10.1
17	4.9	11	10.9
18	5.1	11.4	11.1
19	5	10.9	11
20	5.2	10.7	11.4
21	6.1	13.8	11.9
22	6.7	14	12.8
23	6.6	13.9	13.1
24	6.2	14.2	13.8

The average run time of the two algorithms is shown in Figure 10. With the NSGA II algorithm, the procedure of finding the optimal route for this problem as a multi-objective requires a duration 4times that of a single-objective

Genetic algorithm.

In Figure 11, diagrams of 24 runs (according to table 3) of each objective function by Genetic, NSGA-II, and MPNSGA-II algorithms are shown. In figure 10 chosen 4 runs that have better value. Calculating the convergence of each objective function requires subtracting the objective function in each generation from the previous one. When this value is close to zero, the results are more convergent. According to Figure 11, all algorithms were generally able to converge in iteration near the 20th iteration.

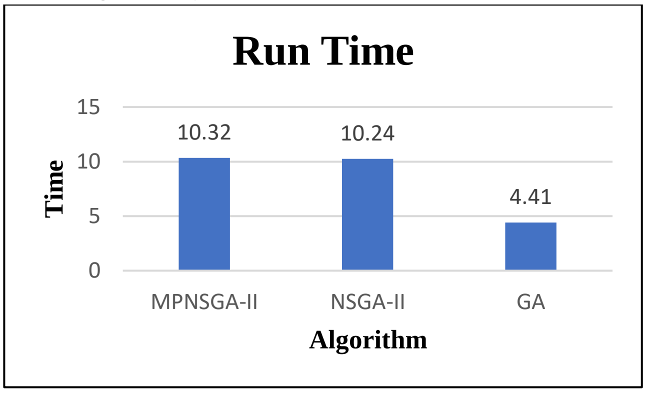
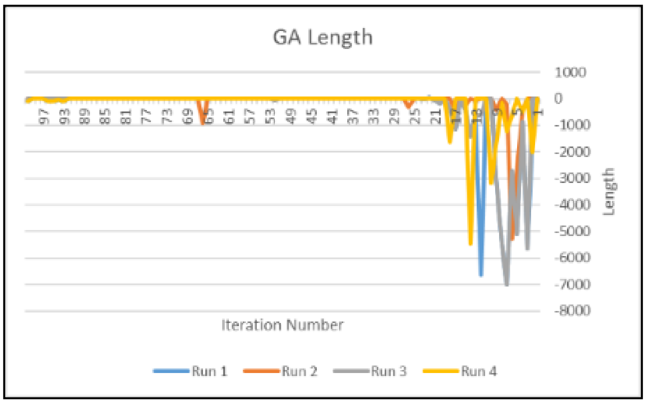
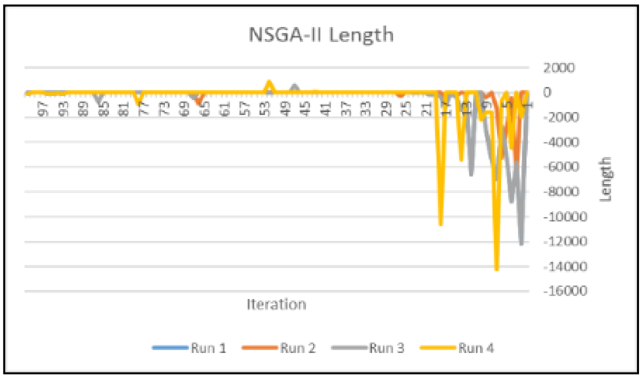


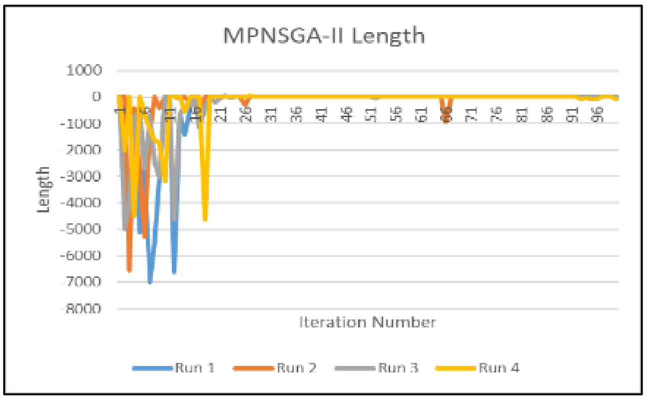
Figure 10. The average runtime of two algorithms



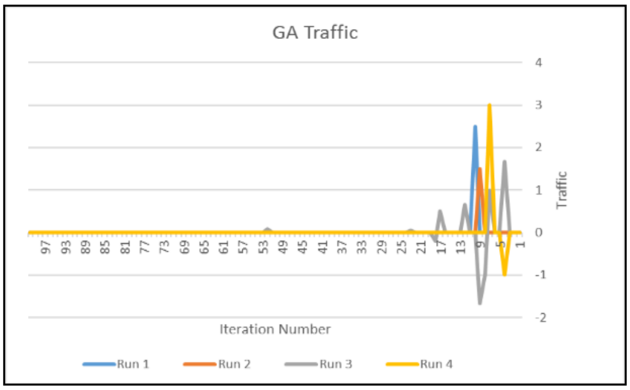
a1



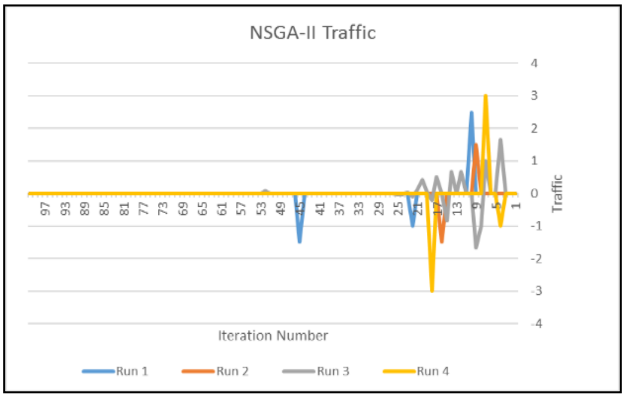
a2



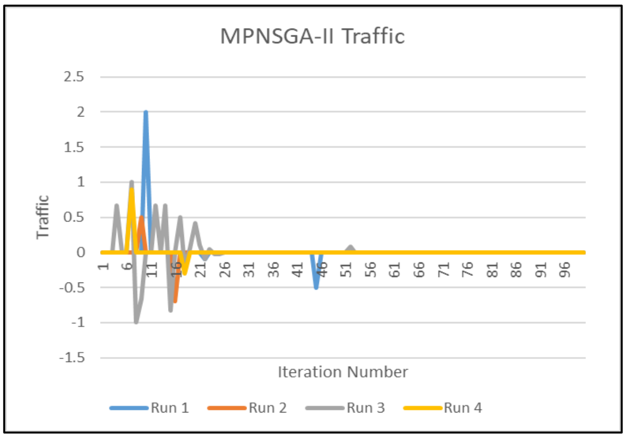
a3


GA Traffic
Traffic
Iteration Number
Run 1
Run 2
Run 3
Run 4

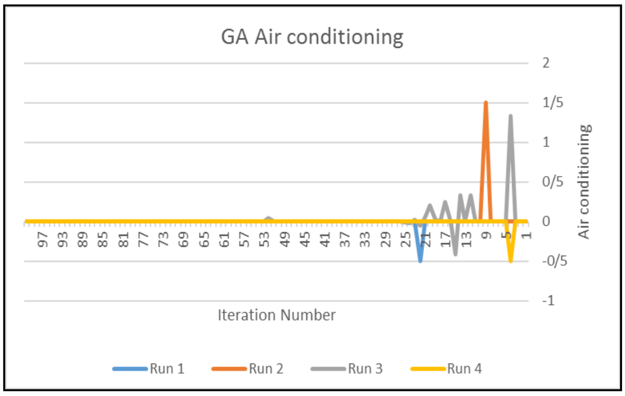
b1


NSGA-II Traffic
Traffic
Iteration Number
Run 1
Run 2
Run 3
Run 4

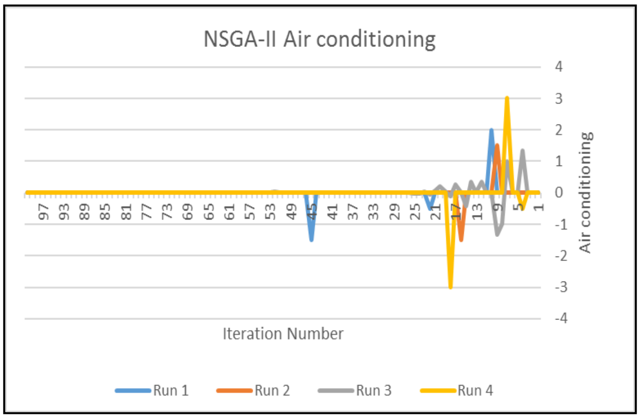
b2


MPNSGA-II Traffic
Traffic
Iteration Number
Run 1
Run 2
Run 3
Run 4

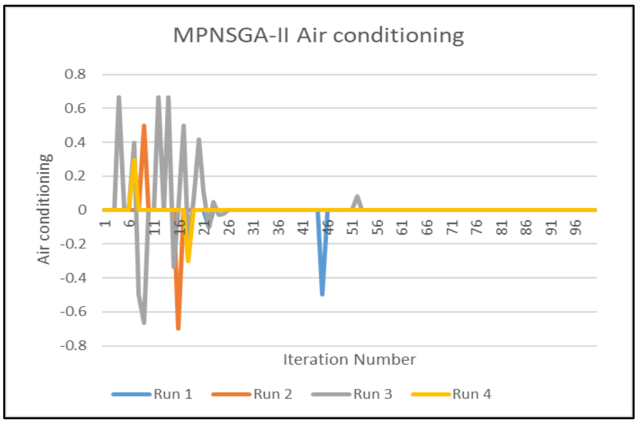
b3


GA Air conditioning
Air conditioning
Iteration Number
Run 1
Run 2
Run 3
Run 4

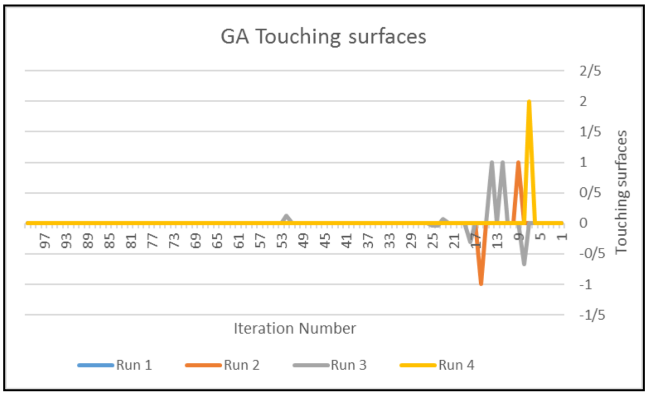
c1


NSGA-II Air conditioning
Air conditioning
Iteration Number
Run 1
Run 2
Run 3
Run 4

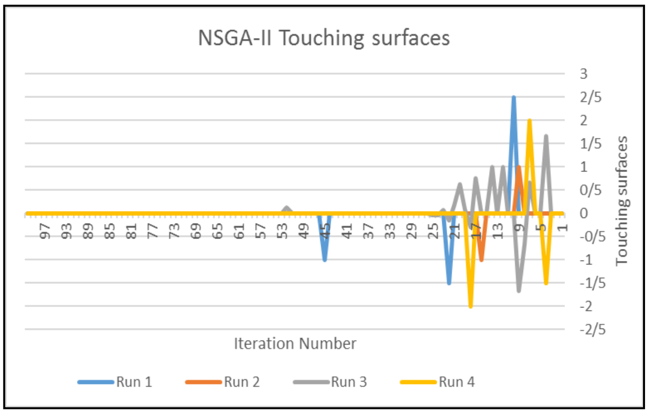
c2


MPNSGA-II Air conditioning
Air conditioning
Iteration Number
Run 1
Run 2
Run 3
Run 4

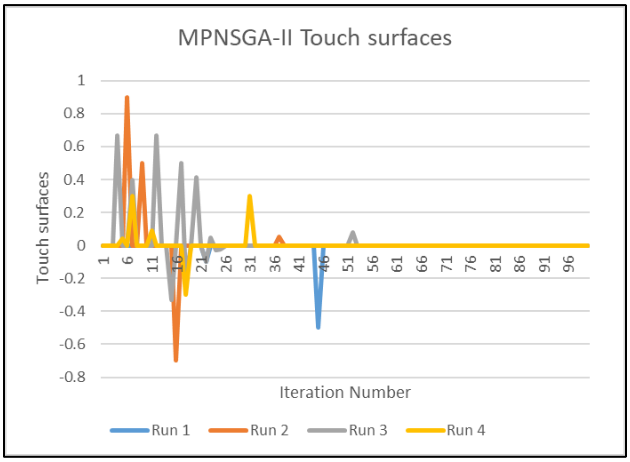
c3


GA Touching surfaces
Touching surfaces
Iteration Number
Run 1
Run 2
Run 3
Run 4

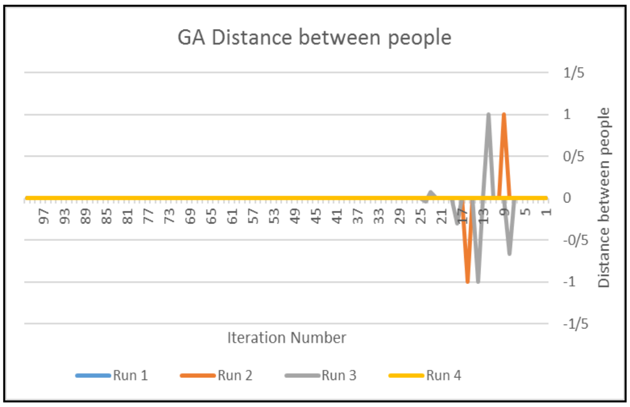
d1


NSGA-II Touching surfaces
Touching surfaces
Iteration Number
Run 1
Run 2
Run 3
Run 4

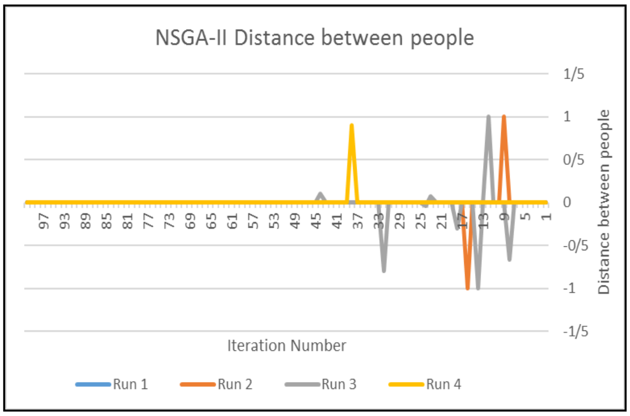
d2



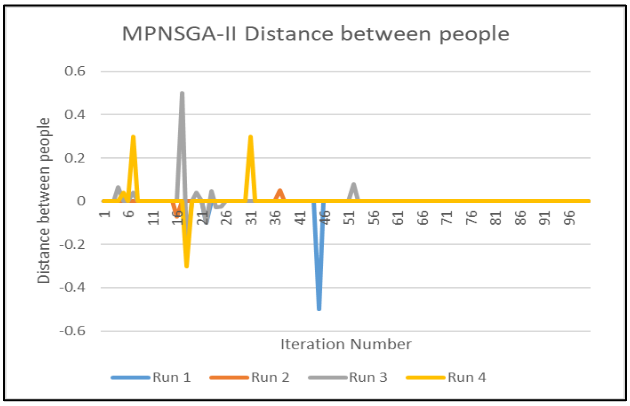
d3



e1



e2



e3

Figure 11. Convergence method of five objective functions in 3 algorithms (a1), (a2), (a3): Length (b1), (b2), (b3): Traffic (c1), (c2), (c3): Air conditioning (d1), (d2), (d3): Touch surfaces (e1), (e2), (e3): Distance between people

6. Discussion

In this study, multi-modal routing based on covid-19 protocols has been discussed. in such a way that existing public transportation is managed by people; That is, in a situation where no policy and plan has been made on the existing situation, to manage Covid-19 in urban public transportation. This means that the passenger should find the route that has the lowest risk of transmission of Coronavirus and at the same time it is efficient.

Efficiency means that the route should have less traffic and length of the route so that the passenger can reach his destination quickly while being safe from the coronavirus. In the studies conducted in connection with covid-19 and the city's public transportation, studies have generally investigated the effects and mode of operation and spread of the coronavirus. Also, in some studies, solutions have been presented for public transportation management during the covid-19 pandemic. These studies are based on the change of existing resources and management on the part of governments. but in this study, based on existing conditions that are immutable, a solution is provided.

Genetic algorithms and their variants are among the basic and powerful algorithms that have performed well in solving many problems. NSGA-II multi-objective algorithm, despite all its advantages and efficiency, has a problem. This algorithm gets stuck in the local optimum. In this study, in order to solve the exploitation problem in the NSGA-II algorithm, a five-parent crossover is presented to a two-parent crossover tea. The results show that the five-parent crossover has been able to create diversity and not get stuck in the local optimum.

7. Conclusion

Because the Covid-19 pandemic happened rapidly, societies did not have time to plan and control it, which resulted in much harm. In this situation, public transportation had a significant role. Using public transportation caused an increase in the virus's spread, and urban planning could not manage the public transportation to control the outbreak of the Covid-19. Thus, using a route in accordance with health protocols is a practical and efficient solution. In this study, routes are proposed proportionally to health protocols. The NSGA-II algorithm has been used to find the optimal route for health protocols. NSGA-II considers five objective functions when finding the optimal route: traffic, path length, air conditioning, surface contact, and individual distance.

Genetic algorithms were used to compare and evaluate the optimal routes obtained from the NSGA-II algorithm for each of the mentioned objective functions. Each objective was applied to the Genetic algorithm as an objective function to test the single-objective routes with the multi-objective routes obtained from the NSGA-II algorithm.

The results show that multi-objective routes according to health protocols obtained from the NSGA-II algorithm are rational and acceptable. Future pandemics might spread around the globe, in which the presented solutions in this study can help citizens to use urban public transportation in a short time. In this state, objective functions should be used according to the health protocols of the virus.

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