Selecting an Optimum Configuration of Urban One-Way and Two-Way Streets Using Genetic Algorithms

Shahriar Afandizadeh Zargari[1], Reza Taromi[2]

[1]Associate Professor, Iran University of Science and Technology, zargari@iust.ac.ir
[2]Iran University of Science and Technology, taromi@iust.ac.ir

Abstract: *Optimization is an important methodology for activities in planning and design. The transportation designers are able to introduce better projects when they can save time and cost of travel for project by optimization methods. Most of the optimization problems in engineering are more complicated than they can be solved by custom optimization methods. The most common and available methods are heuristic methods. In these methods, the answer will be close to the optimum answer but it isn't the exact one. For achieving more accuracy, more time has been spent. In fact, the accuracy of response will vary based on the time spent.*
In this research, using the generic algorithms, one of the most effective heuristic algorithms, a method of optimization for urban streets direction will be introduced. Therefore model of decision making in considered one way – two way streets is developed. The efficiency of model in Qazvin network is shown and the results compared whit the current situation as case study. The objective function of the research is to minimize the total travel time for all users, which is one of the most used in urban networks objectives.

Keywords: *Genetic Algorithms, Network, One-way & Two-way Streets*

1. Introduction

Combinations of one-way and two-way street network in big cities have not appeared suddenly. Their formation and evaluation over the last few decades resulted from varied necessities. Prior to the construction of highways, or in other words from the early days of automobiles invention to the emergence of intercity highways, city center streets as the heart of social activities were the place of community traffic for pedestrians, automobiles, trams and buses. The flow and movement of the transportation vehicles particularly in relation to pedestrians and occupants are coordinated to ensure maximum safety and efficiency. Speed restrictions in congested and residential areas are indicative of the premise. It is with this premise that street networks of one-way and two-way combinations have become attractive propositions (Du and Paradalos, 1993).

The emergence of highways provided many benefits for people and businesses alike. Moreover, when workers moved to the suburb in search of bigger and less expensive houses, coordination of users and commuters in the central streets of cities were disturbed to the extent that more attention had to be given to simplifying the movement of these passengers. This happened when the old and narrow streets of cities were unable to cope with the relentless burden of demands posed by commuters in the morning and in the afternoon. This explosion in movement and transportation inevitably resulted in the design optimization of streets and transportation networks.

Drezner and Wesoloswky (1997) and

Drezner and Salhi (2000, 2002) attempted to construct a suitable configuration for the optimization of the best situation for one-way and two-way networks with the specific intention of minimizing the total travel time for all users. Each street of interest is supposed to be equivalent to a link, composed of three members. It must be added that no limit is considered for the network, except that between each origin and destination, a path must exist.

Lee and Yang (1994) believe that the difficulty of the problem is in the large number of the configurations and not in the network limitations. They tried to introduce a model for the delay in street networks in which the effect of making the streets one-way and two-way is more obvious. Lee and Yang then employed the heuristic algorithm based on the simulated annealing method to solve the problem.

In a detailed report produced by The Transport Research Centre at Sharif University of Technology (1997) the selection of one-way streets for a populated northern city in Iran, Mashad, is evaluated. The chosen method is derived and distilled from a range of possibilities and the collective knowledge of experts in the field. The most important attraction of the adopted selection methodology in the design of one-way and two-way streets stems from the fact that it addresses the limitations associated with the network.

Total travel time is based on traffic volume and travel time in each street in a transportation network. Traffic volumes and travel times in streets are derived from equilibrium traffic assignment. In this research minimization of total travel time is the objective target. This minimization problem can be shown as in equation (1):

$$\begin{aligned} & Min \sum_{a \in A_Z} x_a(Z) t_a^Z (x_a(Z)) \\ & subject \quad to: \\ & Z = \{(z_1, z_2, ..., z_k) | z_i \in d_i, i = 1,...,k\} \\ & X(Z) = Assign(N(Z), D) \end{aligned} \qquad (1)$$

Where:

DS: Streets in a city network
d_i: {1, 2, 3}
z_i: the situation of member i in the city network, 1 for two-way streets, 2 for one-way streets from start to end of street, 3 for one-way streets from end to start of street.
N (Z): city network based on z_i
x_a (Z): traffic Volume in street "a" in the city network based on z_i
X (Z): traffic volumes in all streets in a city
t_a^Z: Volume-Delay function in street "a" in the city network based on z_i
Assign (N,D): Equilibrium traffic assignment procedure which is described in equation (2).

$$\begin{aligned} & MinZ(X) = \sum_a \int_0^{X_a} t_a(w) dw \\ & S.t. \\ & \quad \sum_k f_k^{rs} = q_{rs} \qquad \forall r, s \\ & \quad f_k^{rs} \geq 0 \end{aligned} \qquad (2)$$

Where:

A: all of the streets in the city network and "a" is a member of it
R: all of the Origin centroids in O-D matrix and "r" is a member of it
S: all of the Destination centroids in O-D matrix and "s" is a member of it
rs: is an O-D pair
K_{rs}: all routes between "rs" origin-destination and "k" is a member of it
q_{rs}: O-D matrix between "r" and "s"
t_a: travel time in street "a"
f_k^{rs}: Traffic volume in street "a" belong to route "k" between "r" and "s"

δ_{ak}^{rs}: Equal to 1 if street "a" is a member of route "k" between "r" and "s"
Xa: equilibrium traffic flow which is calculated by equation (3)

$$X_a = \sum_r \sum_s \sum_k f_k^{rs} \delta_{ak}^{rs} \tag{3}$$

2. Genetic Algorithm

2.1 Encoding the Answers

In nature, different kinds of creatures exist. The differences appear in the chromosomes of the creatures and thence results diversity in their structure and behavior, which affects their procreation. The more able creatures have a higher rate of procreation. The most common way of encoding and showing the chromosomes in the genetic algorithm is through the use of a single binary string. In this method every answer or parameter is encoded as a binary string (of either 0 or 1) and these strings are connected continually to create a chromosome. Although the binary encoding system is commonly used presently, more and more consideration is given to different encoding methods.

In this project, instead of binary encoding system (0 or 1), the (1, 2, 3) encoding system is used. In this system, one digit string is considered by selecting one of the "1", "2" or "3" numbers. Here, digit "1" signifies a one-way street from beginning to ending; digit "2" shows a one-way street from ending to beginning, and digit "3" refers to a two-way street. This method of encoding is used in this research.

2.2 Fitness Function

Fitness function is the relation between the genetic algorithm and the problem in hand; also it provides the evaluation mechanism of each chromosome. Fitness function gives a specific value to each member of the population, and this value is indicative of its fitness. In most cases, fitness function is the same as purpose function of the problem, or is a direction of it. Since, the purpose of this project is to minimize the total travel time for every users, this purpose function could be used as the fitness function. Therefore, the fitness function of this project is considered as:

$$\sum_{a \in A_z} x_a(z) t_a^z(x_a(z)) \tag{4}$$

Where:

$x_a(z)$: Equilibrium flow in link "a" while selecting configuration "z" in street network.
A_z : "z" configuration links complex in street network and "a" a link of it
t_a^z : Volume-delay function in link "a" while the configuration "z" for street network is selected.

It should be mentioned that the amounts "x_a" and "t_a" in each link are obtained after solving the equilibrium traffic assignment issue.

2.3 Selection Mechanism

The mechanism determines the members to be selected for generation or the ones allowed appearing without change in new generation. In roulette wheel selection method, people are selected according to their qualifications. Those with more qualifications have more possibility to be selected. In this method by calculating the summation of the amounts of qualifications, each member is equivalent to one subinterval based on its own qualification in the [0, summation of qualification] interval. By choosing a random number in the above interval, the number of the population, in the interval in which the random number exists, will be selected.

In rank selection method, qualification of each member has no effect on the member selection and the selection of members is done completely randomly. In this method, first a random number between 1 and the number of the members is selected, then that member of the group with the same equivalent row of the random number is selected as a result of the rank selection method.

2.4 Genetic Operators

Reproduction operator consists of a copying process in which a number of the existing generation members are transferred directly and systematically to the next generation.

Crossover operator selects a pair of members with the use of selection mechanism and in a random manner, and generates new members by combining the two. In a one point crossover method, a random point along the strings (chromosomes) is selected for reproduction and then one part of the answer string is selected from first string and the other part from the second. A combination of these two parts makes the new string. In the two points crossover method, two random points for reproduction are selected and then the answer string is generated. In the uniform crossover method, a combination of the new string points is done in a random manner from the two primer strings. In the arithmetic crossover method, corresponding genes on both chromosomes which are encoded in the form of binaries are combined using the mathematical operator "AND", so the new chromosome is generated.

Mutation is a process in which by changing one or more genes of a member (parent), a new member is gained, and its role is to prevent the convergence of the problem to local answers and to provide the possibility of analyzing the entire points of the search space. In the bit inversion mutation method, one of the existing genes of the chromosome string is randomly selected and changed. In the order changing mutation method, first two genes on an existing chromosome string are selected and the amounts of those two genes are changed with another.

3. Suggested Model

The genetic algorithm based model employed here is formed of three parts. The first section consists of reading the database, arranging the model parameters, creating a network for the first population, controlling the possibility of the created network and providing information for traffic assignment. There is no need to encode any network for this part.

The second section comprises of receiving the input data of traffic assignment, results of traffic assignment, finding travel time and link volumes, and calculating the total travel time for all users. Traffic assignment in this section is accomplished by referencing to the memory of assigned network, and just in case the input network has not been assigned previously traffic assignment is accomplished. In this section, networks are not encoded.

The third part covers the use of genetic operators for the decision of network selection, crossover, reproduction and mutation. In this section first the network is encoded and after implementation of genetic operators, if possible, they are decoded. At the end of the modeling, output results are saved into a file and the run of the model is accomplished. For a clear understanding of

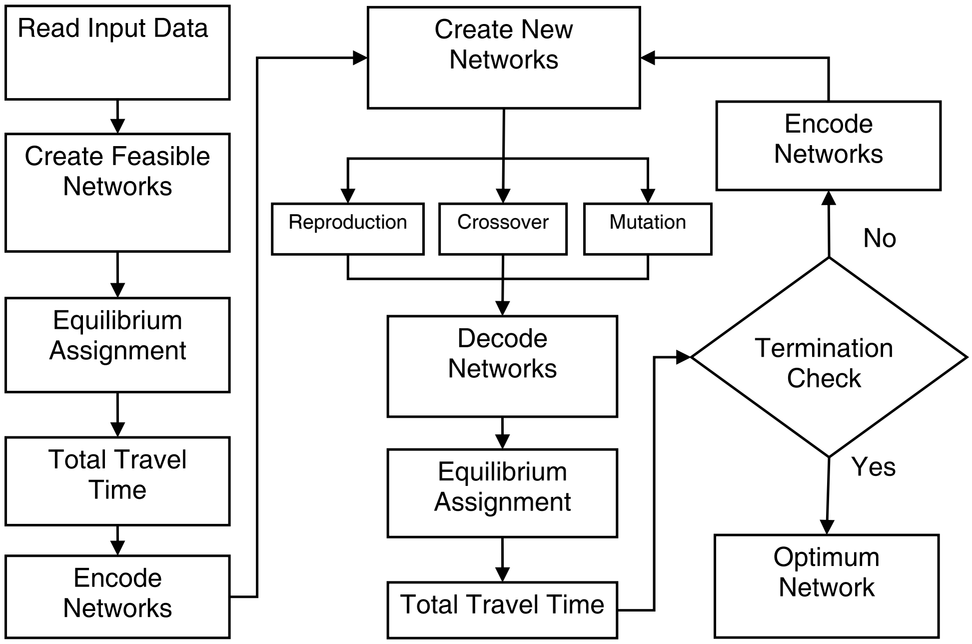

Figure 1: The model developed for optimization based on genetic algorithm.

the communication between model components, the model flowchart depicted in Figure 1 can be illustrative.

The model, as outlined in Figure 1, is codified using Visual Basic language. The simulation program reads its database as text files and also represents generated computational results as text files. It is capable of modeling a complete urban transportation network and also capable of considering all the genetic operators embraced within it.

3.1 Case Study

Knowing that the main purpose of this study is to formulate an effective method based on genetic algorithm so as to enable a proper answer for the configuration and direction of streets in urban networks. In order to assess and validate the reliability of the suggested model, the street network of Qazvin, a city situated in the northern part of Iran, is considered for this purpose.

Here, in order to conduct a comprehensive transportation and traffic study, the city is divided into 105 traffic zones. The existing situation of the street network for the city is a network consisting 411 nodes, of which 105 are centroids, 31 dummy nodes, 256 regular non-signalized nodes and 19 regular signalized nodes. Also 1131 links connect the network nodes to each other, of which 266 are connector links. The public transport network of the city has 17 bus lines. In the link network of the city 12 different types of street, such as arterial, collector, etc, are considered. The matrix of origin-destination trips for the morning peak-hour is consisted of 9 different matrices, separating pedestrian, truck, motorcycle, bicycle, pickup, car, taxi, bus and minibus.

3.2 Selection of Target Streets

In order to deal with the selection of target streets, first the volume capacity ratio, V/C, is chosen larger than 1 so as to show the function of the existing situation of the street network of the city. In the urban streets section of the highway capacity manual a V/C ratio equal to 1 is known as the level of service E, and a V/C ratio between 1 and 1.2 is designated as the level of service F. Therefore, selection of target streets is done on the group consisting streets with the F level of service. The application of the above measurement is such that, first the existing streets network of the city is performed with the emme/2 software (1994) and the "Characteristics of Links" file and the "Volume to Capacity" ratios for all network links are specified. Then, those links which meet the required measurement are separated and a target street is selected which covers 58 streets in the city since, in the definition of street network, usually for each street two roundtrip links are considered; the aforementioned 58 streets comprise 116 links, which form nearly 10 percent of the 1131 links of Qazvin city street network.

3.3 Selection of Parallel Streets Complex

Parallel streets are those with dependent directions to each other. Streets of parallel complex should be all one-way in one direction or all one-way in other direction or all two-way streets. Selection of parallel streets is often based on network limitations and its most important reason is to prevent the confusion of drivers. In this research, selection of parallel streets is done using heuristics and engineering judgment as well as limiting the two ends of the two arterial streets of the complex. In the selected parallel streets complex, there exists five subclasses with one member, 13 with two members, five with three members and three with four members.

3.4 Sensitivity Analysis and Optimization

In order to reach the best crossover of operators, 16 possible combinations considered have been derived from the followings:

-Two methods for population selection: consisting roulette wheel selection and rank selection.

-Four methods for crossover: consisting single point crossover, two points crossover, uniform crossover, and arithmetic crossover.

-Two mutation methods: consisting bit inversion and order changing methods.

Here, in addition to determining the most proper crossover of operators, the most proper population is also distinguished. The method to select the best population is that the result of above 16 states for 5, 10, 15, 20, 25, 30 and 35 populations illustrates the proper population. The number of generations (iterations) is also considered as 100.

In view of the fact that at the beginning of the sensitivity analysis there was an exact estimation of different percentages of genetic operators, the percentage of these operators were assumed as below:

-20% of the best members of the existing generation are directly replaced in the new generation (Reproduction).

-50% of the new generation are created using crossover.

-30% of the new generation are created using mutation.

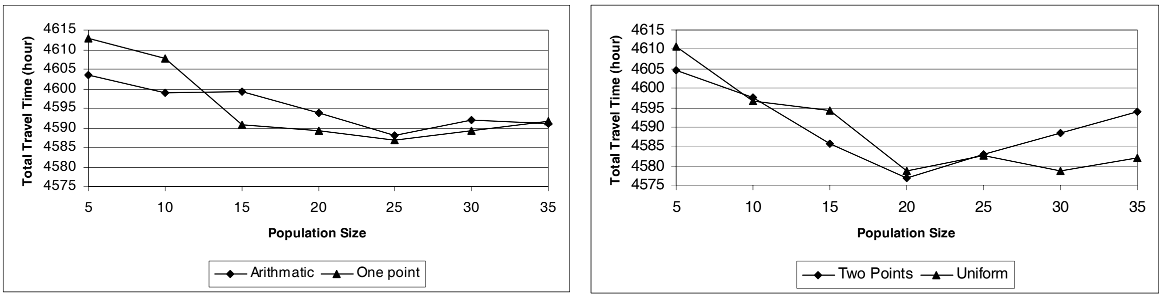

Figure 2: Convergence levels of the crossover consisting bit inversion mutation and rank selection method.

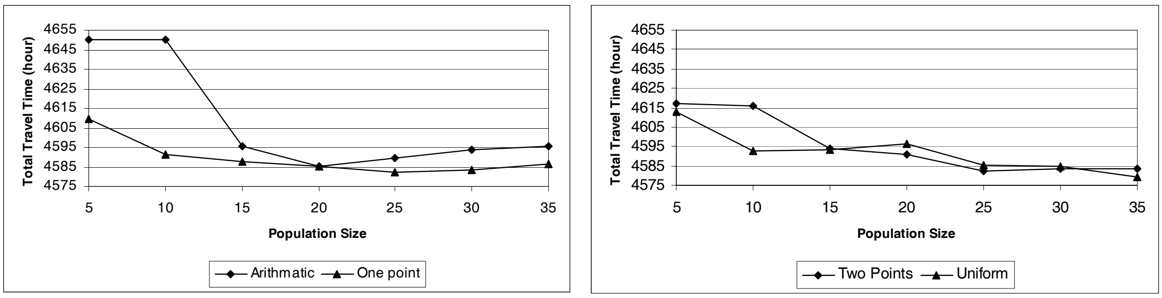

Figure 3: Convergence levels of the crossover consisting order changing mutation and rank selection method.

After the implementation of the model for the 16 described choices and for different populations, two combinations are selected as the best for model accomplishment:

-Selection using roulette wheel method, uniform crossover and order changing mutation

-Selection using rank selection, one point crossover and order changing mutation.

Convergence levels of the above two crossovers are illustrated in Figures 2 to 5.

3.5 Finding the Best Percentage of Genetic Operators

After selecting the two best combination operators, they are used in the sensitivity analysis of the model relative to the percentage of the operators. For the analysis of model sensitivity to the percentage of the operators, three different conditions are considered which include: 10%, 20% and 30% reproductions.

Each of these three conditions for the mutation percentages of 5, 10, 20, 30 and 40 are analyzed using the model. The computational results reveal that the "selection using roulette wheel selection, uniform crossover and order changing mutation" combination for 20 percent reproduction, in addition to having a proper convergence trend, provides better answers. The convergence levels of these combinations are exhibited in Figure 6.

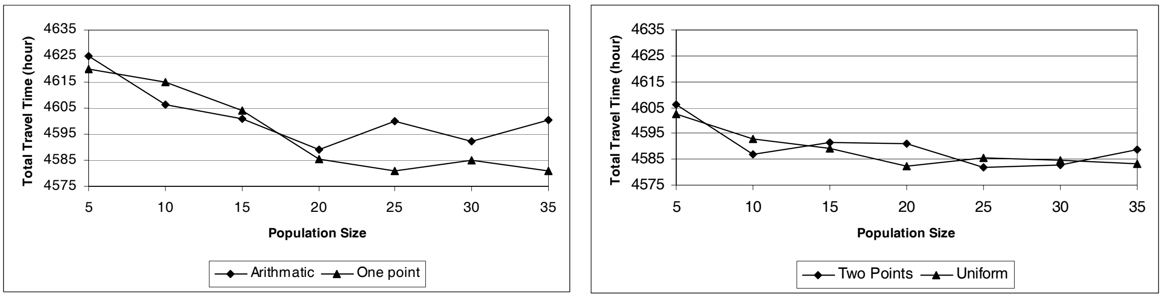

Figure 4: Convergence levels of the crossover consisting bit inversion mutation and roulette wheel selection method.

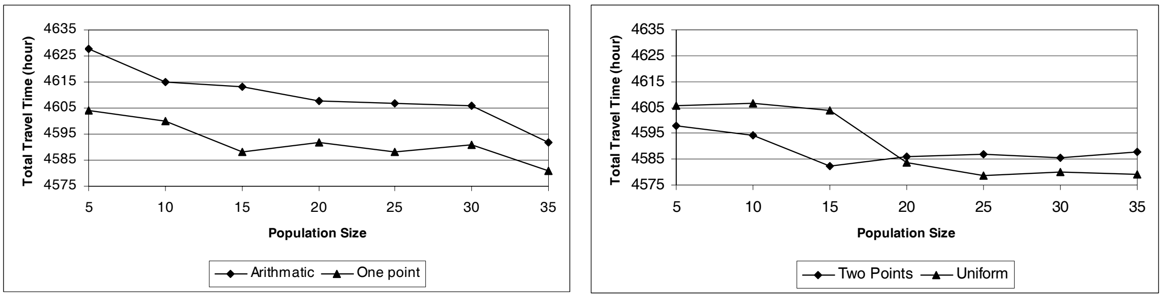

Figure 5: Convergence levels of the crossover consisting order changing mutation and roulette wheel selection method.

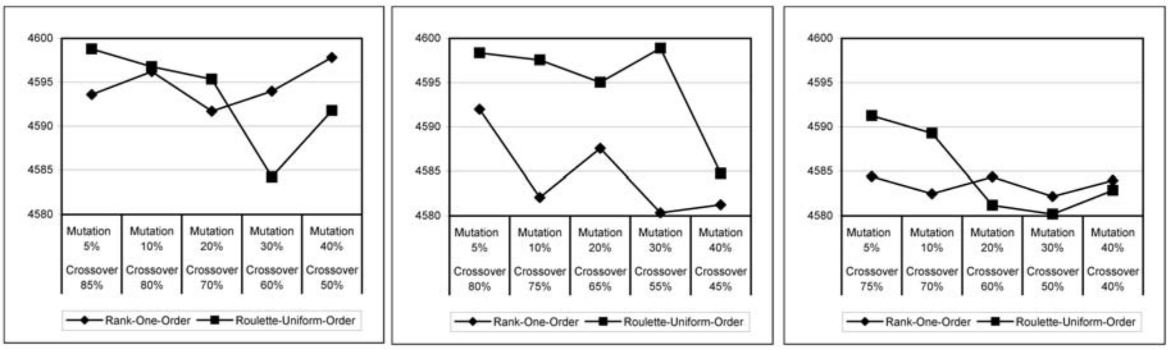

Figure 6: The convergence levels of the suggested combination.

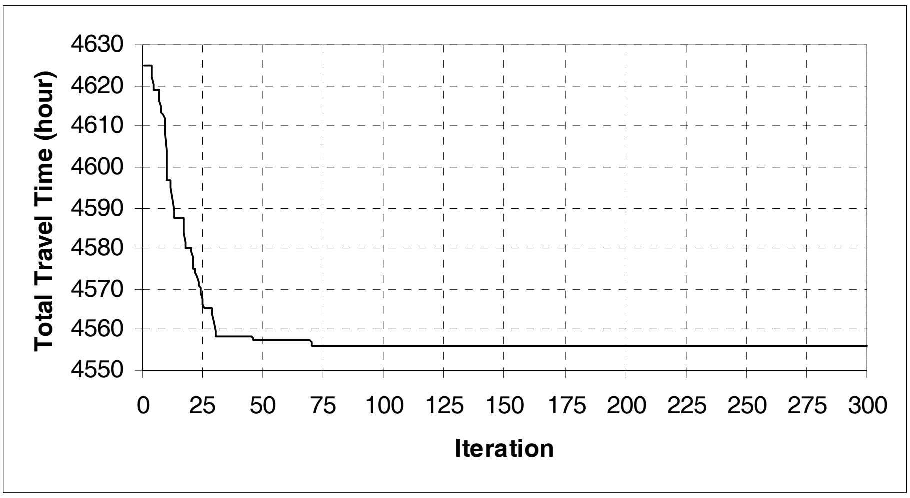

Figure 7: Details of convergence levels to optimal answer.

3.6 Model Results and Selection of the Best Streets Network

Having formulated the different parameters and selected the roulette wheel selection method for 20% reproduction, 50% uniform crossover and 30% order changing mutation, the final phase of modeling can be accomplished. To ensure convergence of results, the number of iterations is set at 300. Details of convergence levels to optimal answer and the best answer in each level of modeling are highlighted in Figure 7. Inspection of results displayed in Figure 7 reveals that after 70 iterations the model solution reached convergence.

For further understanding of the suggested model, the existing street network and the suggested street network are shown, respectively, in Figures 8 and 9. A comparison of the two rival arrangements demonstrates the following points:

-From the 58 intended streets of the existing network, 24 streets are one-way and 34 are two-way.

-From 58 chosen model streets, 44 are one-way and 14 are two-way

-In the existing network, the direction of 7 one-way streets has not altered

-In the existing situation the direction of 14 one-way streets has reversed

-The direction of 11 two-way streets in the existing network has not changed

-In the exiting network, 3 one-way streets are changed to two-ways

-In the existing network, 23 two-way streets have changed to one-ways.

3.7 Computational Results

The genetic algorithm based model presented here results the whole operation of network development, its control, preparation of data and traffic assignment using a computer

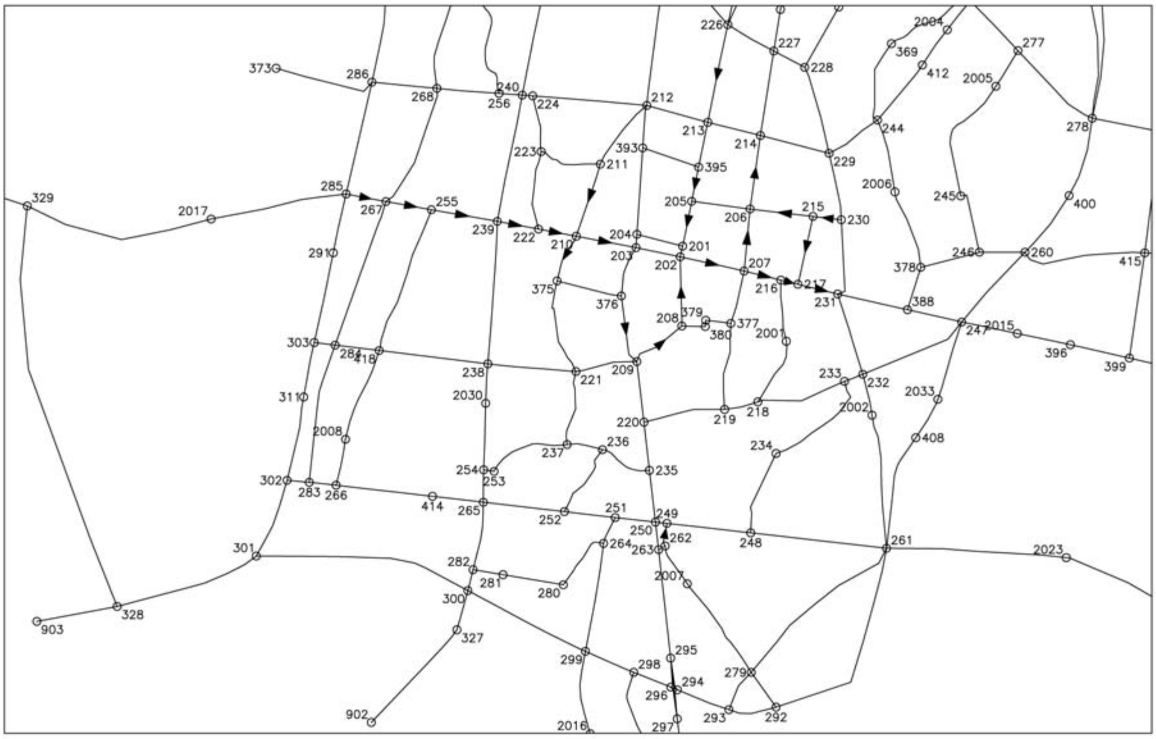

Figure 8: Existing Qazvin street network and the direction of one-way streets.

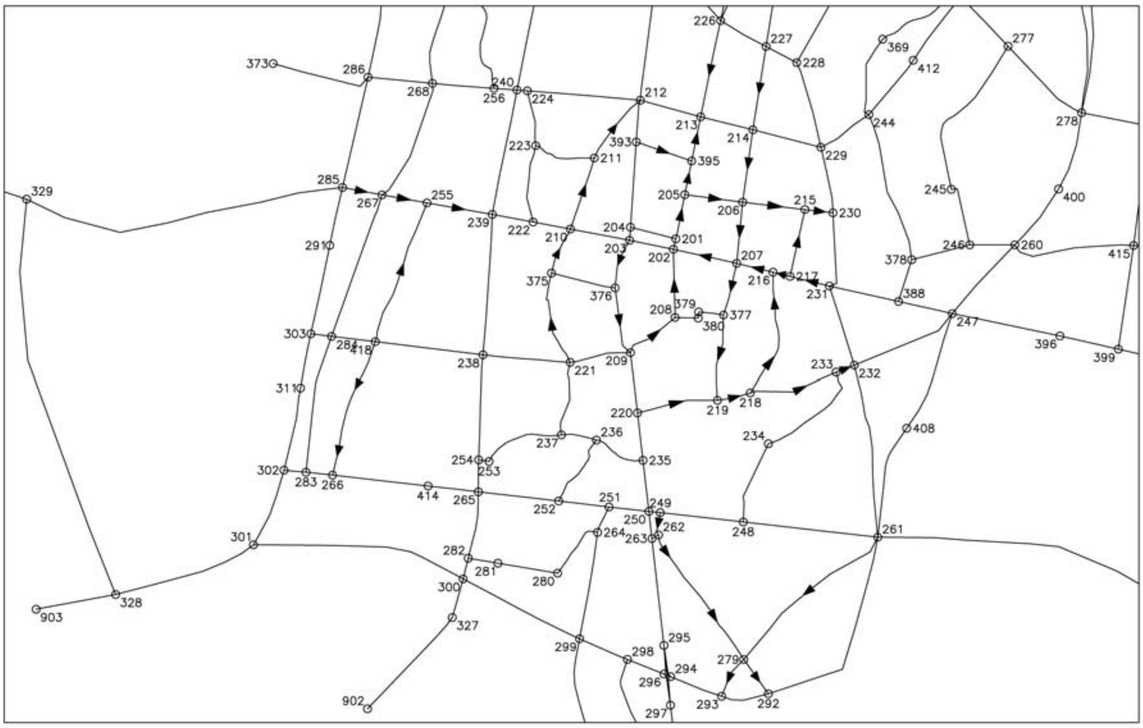

Figure 9: Suggested Qazvin street network and the direction of one-way streets.

program developed especially for this research in 25 seconds. Also, this model avoids traffic assignment for repeated networks, using a memory list which keeps the results of traffic assignment of previous networks.

Since the population used in the final run is 25 and the number of iterations is equal to 300, so a maximum of 7,500 (=25×300) network is considered.

The final run of the model with the stated conditions lasted four hours. If the complete counting method to reach the optimum answer is used, 2,579,890,176 ($=3^9\times2^{17}$) different networks would be developed and analyzed which would take 2,045 years.

It is evident that reaching the optimum answer in such cases is practically impossible. Genetic algorithm in this research, in addition to requiring a considerably shorter and affordable time, facilitates an acceptable and effectively optimum answer. The effectiveness of heuristic optimization methods, in different areas, has lead to the use of genetic algorithm based methods. Even in some cases, different multi-optimization methods are used and some of such methods give better answers compared to others.

4. Comparison with emme/2 Software

Because of omitting public transportation in Visual Basic based program, another transportation network considering public bus transit routes were developed in emme/2 software. This network is the result of Genetic Algorithm based mode. Results of emme/2 software are total delay, total travel, free flow travel time, emission, fuel consumption and volume and travel time on each street and so on.

After running emme/2 program for existing network and suggested network of Qazvin city, total travel time decreases from 4369 hour (in morning peak hour) to 4239 hour (in morning peak hour). This means that if the suggested model is employed then the total travel time for all users in a peak hour decreases by 130 hours. It is worth pointing out that the reduction in travel time is a consequence of street direction management, which is not expensive to implement. Assuming that over a 24-hour period 8 to 10 hours constitute peak period, then the total travel time is reduced by some 1,000 to 1,300 hours. Multiplying this travel time by the average of the value of time of city, which is estimated to be 4,000 Rials (equivalent to $0.45), provides annual cost savings of over $200,000, a considerable sum for a city of Qazvin size.

The difference between results of Visual Basic based model and emme/2 software for existing network and suggested network relates to considering public transit buses in emme/2 software instead of Visual Basic based model.

For further understanding, Figure 10 illustrates the ratio of travel time over free flow travel time for each street in existing situation and Figure 11 illustrates this ration in suggested network.

Other emme/2 results are total kilometer, free flow travel time and total travel time for each scenario as shown in Table 1 for existing situation and Table 2 for suggested network for Qazvin 3 municipal districts.

As shown in Table 1 and Table 2, total kilometer for all vehicles in Qazvin city will be decreased from 365653 to 360560 by

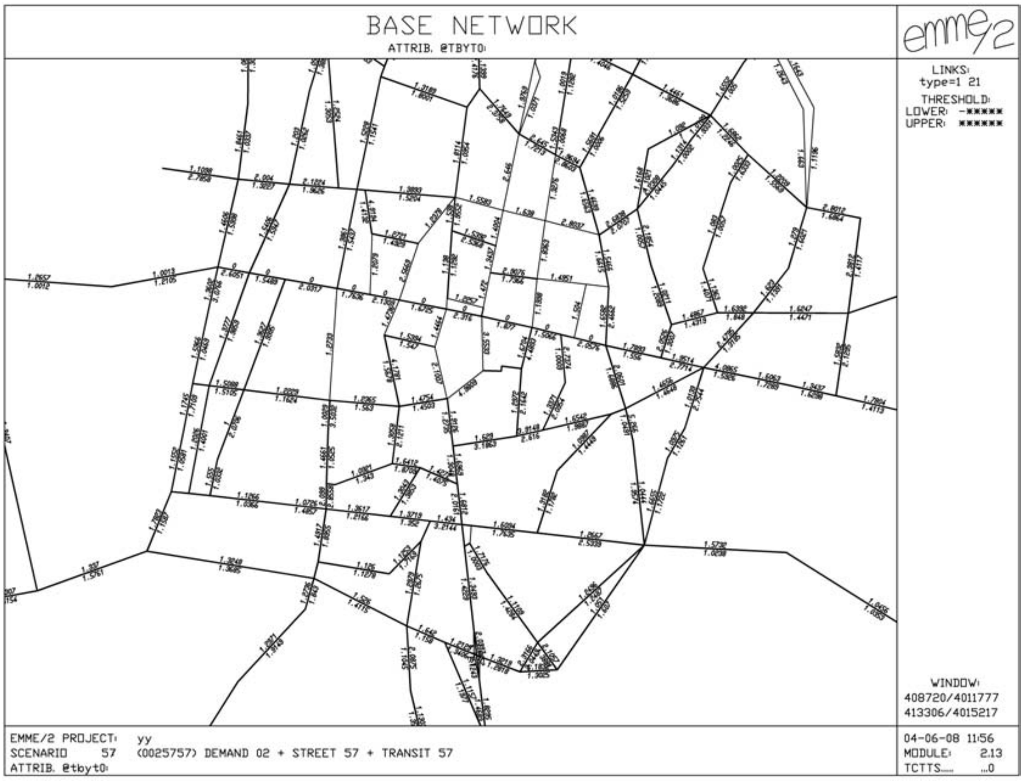

Figure 10: Emme/2 software results of travel time for existing situation.

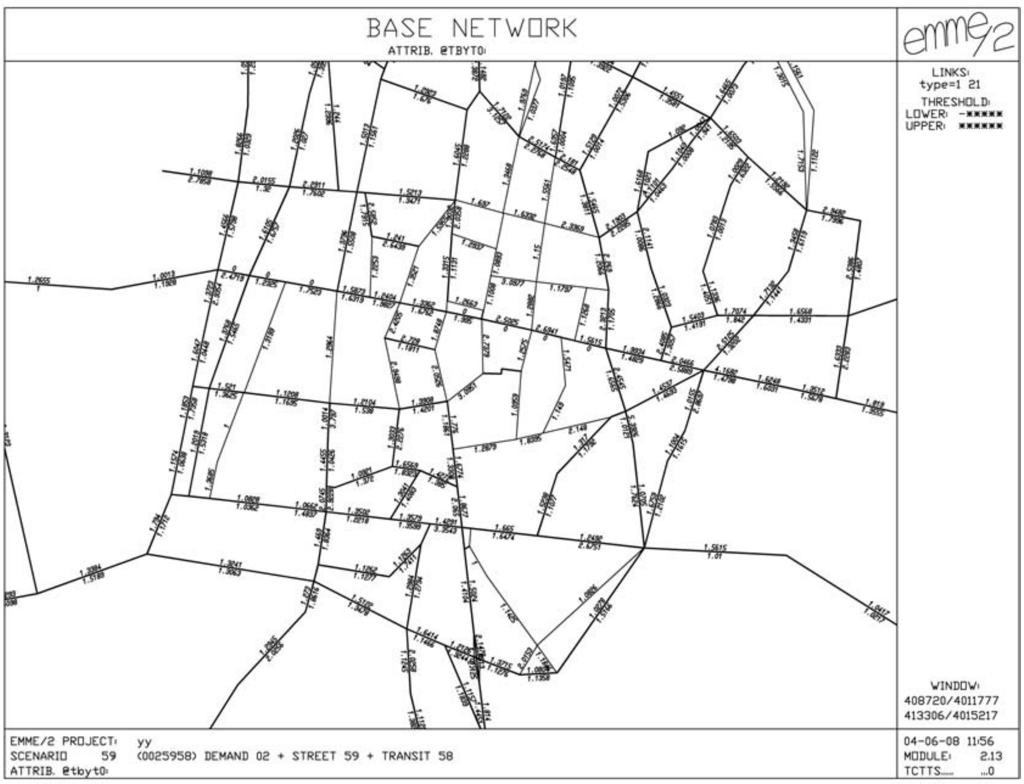

Figure 11: Emme/2 software results of travel time for Suggested situation.

Table 1: Qazvin transportation parameters in existing situation.

Municipal District	Total Kilometer (Vehicle-Kilometer)	Average Free Flow Speed (Kilometer per hour)	Average Speed (Kilometer per hour)	Free Flow Travel Time (T0)	Total Travel Time (T)	T-T0
1	168368	57.9	35.6	1240	2020	779
2	165814	53.3	34.9	1327	2028	701
3	31472	53.4	41.8	251	321	70
Total	365653	55.3	35.7	2818	4369	1551

Table 2: Qazvin transportation parameters in suggested network.

Municipal District	Total Kilometer (Vehicle-Kilometer)	Average Free Flow Speed (Kilometer per hour)	Average Speed (Kilometer per hour)	Free Flow Travel Time (T0)	Total Travel Time (T)	T-T0
1	161992	57.7	36	1188	1906	718
2	167054	53.4	35.1	1324	2013	689
3	31513	53.4	41.8	250	319	70
Total	360560	55.2	36	2762	4239	1477

Table 3: Qazvin fuel consumption and emissions in existing situation.

Vehicle Type		Motorcycle	Private Car	Taxi	Pickup	Bus	Transit Bus	Truck	Sum
Fuel Consumption	Gas (Liter)	719	20227	7455	7983	-	-	-	36384
	Gasoline (Liter)	-	-	-	-	17282	12500	10487	40269
Emission	CO (kg)	468	5569	2665	1703	-	-	-	10405
	HC (kg)	261	477	201	150	-	-	-	1089
	NOx (kg)	-	150	31	51	617	477	396	1722

Table 4: Qazvin fuel consumption and emissions in suggested network.

Vehicle Type		Motorcycle	Private Car	Taxi	Pickup	Bus	Transit Bus	Truck	Sum
Fuel Consumption	Gas (Liter)	731	19860	7421	7833	-	-	-	35845
	Gasoline (Liter)	-	-	-	-	17111	12329	10374	39814
Emission	CO (kg)	453	5551	2663	1709	-	-	-	10376
	HC (kg)	254	477	201	150	-	-	-	1082
	NOx (kg)	-	145	30	50	609	468	390	1692

using the suggested network. It means the suggested network should decrease 5000 vehicle-kilometer in morning peak hour.
Decreasing fuel consumption and emissions are other improvements of suggested network. Total fuel consumption and emissions from emme/2 software for existing situation and suggested network is shown in Table 3 and Table 4.

Total gas consumption in morning peak hour is about 36384 liters and total gasoline consumption is about 40269 liters in existing situation. By choosing the suggested street network these fuels consumption will decrease to 35845 liters for gas and 39814 liters for gasoline. Hence, 539 liters of gas and 455 liters of gasoline will be saved by using the suggested network in morning peak hour. If the full day fuel consumption considers 8 to 10 peak hour then total fuel reduces by selecting suggested network would be 4800 liters per day for gas and 4000 liters per day for gasoline. So total yearly fuel saved by selecting suggested network would be about 1.75 million liters per year. Multiplying fuel saving time by the average of fuel price, which is estimated to be 80 cents per liters, provides annual cost savings of over $1,400,000 per year.

By choosing the suggested network, air pollutions will be reduced from 13216 kilograms per peak hour to 13150 kilograms. This 66 kilogram loss of air pollutions in peak hour means about reducing 600 kilograms per day and 220,000 kilograms per year.

5. Conclusions

Finding the optimal configuration of street directions in urban streets using the Scenario Making method is becoming more difficult with the increase of in the complexity of street design. Evidently, there is more desire to utilize new optimization methods in such situations.

This research attempted to develop a model on the basis of genetic algorithm for the optimization of urban streets network and for this the network of Qazvin, a city in Iran, is used as a case study so as to demonstrate the effectiveness of the adopted modeling approach. It is shown that using the Scenario Making method for finding the best configuration of streets is practically impossible, but the presented genetic algorithm based model can facilitate a proper answer for the posed problem effectively. In view of the fact that no similar research can be identified, therefore it has not been possible to compare these findings with literature data but the results reveal the capability and attractiveness of the genetic algorithm in handling complex and problematic transportation issues.

Further, by comparing different genetic operators it has been established that in the formulation of the direction of city streets, roulette wheel selection, uniform crossover and order changing mutation operators provide faster optimum solutions compared to other operators.

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