Koc. J. Sci. Eng., 6(1): (2023) 78-88 https://doi.org/10.34088/kojose.1159113

Kocaeli University

Kocaeli Journal of Science and Engineering

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Optimization of Traffic Network Signal Durations with Heuristic Algorithm and the Effect of Number of Individuals

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Article Info

Research paper

Received : *August 8, 2022*
Accepted : *December 27, 2022*

Keywords

Differential Evolution Algorithm
Heuristics Algorithms
Modeling and Simulation
Traffic Lights Optimization
Traffic Network Simulation
Soft Computing

Abstract

In the traffic network that we frequently use in our daily life, the primary demand of people has been to reduce the time they spend in traffic and to travel to the points they want to reach as quickly as possible. Developing countries want to meet this demand with the least cost in order to meet this demand. This study aims to manage the traffic network with the best times by optimizing the traffic signal durations in order to minimize the travel time for a road network chosen as a benchmark. For the optimization process, it is aimed to run a population-based heuristic algorithm with different numbers of individuals and obtain the best travel time. With the help of an open-source code traffic simulation program, which was run by modeling the benchmark road network, the received traffic data was also visually analyzed and compared. The effects of the heuristic algorithms applied with different numbers of individuals on the travel times according to the starting-destination points were examined before and after the optimization. As a result of the study, it has been observed that travel times and traffic signal times can be reduced with heuristic algorithms. Based on both numerical metrics and visual results, it has been determined that optimized traffic light durations give better results than non-optimized ones.

1. Introduction

Traffic is the name given to the structure that includes various vehicles and the units that manage these vehicles, and that we have to use in order to travel to the points we want to reach in our daily life. In developing countries, the increasing number of vehicles and the inadequacy of road capacities for travel demands have led to an increase in the time spent on transportation and the problem of traffic road networks. It has been stated that the increased transportation times and the length of time spent in traffic have a negative effect on people and lead the authorities to seek to solve this problem [1]. The authorities, who are in search of different methods, have proposed methods such as expanding the road capacity, increasing the units that control the traffic instantly, and methods that are high in cost and open to human error [2]. However, since these methods are both costly and non-continuous applications, searching for different solution methods is reasoning. Optimizing the traffic lights in the road network system stands out among them in terms of both cost-effectiveness and applicability. For this reason, many researches and studies have been carried out to optimize the related parameter of the traffic network and to minimize the travel time.

In the studies examined, it has been seen that heuristic approaches give very good results in optimizations for the traffic problem. For example, in [3], Rutger et al. aimed to find the best routes for vehicles and obtain the best travel times by using Ant Colony Optimization to optimize travel times. Jindal and Bedi, on the other hand, aimed to avoid congested roads and direct vehicles to less-used roads by using route information to minimize traffic congestion in a city using the Hybrid Ant Particle Optimization (IHAPO) heuristic approach [4]. They tested it using SUMO for traffic simulation and reported that the travel time is reduced significantly. In [5], the authors aimed to solve the travel problem of congested

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roads by applying low-level and high-level optimization operations on the test network of Allsop and Charlesworth [6]. The Allsop and Charlesworth test road network, which was used in many studies, was determined by the authors as a benchmark in optimization for this study. Sheffi et al. [7] performed signal duration optimization by keeping the traffic flows constant. Başkan et al. [8], on the other hand, aimed to minimize traffic signal durations reducing travel times to the most suitable level for vehicles with the two-layer optimization method called TRACOM, which they developed using the Allsop and Charlesworth road network. The authors drew attention to the importance of using traffic lights with optimized duration, where vehicles perform better than non-optimized traffic lights.

In the current literature, studies on traffic optimization continue. Control of traffic lights in a road network of a large city is an extremely complicated task. For this reason, it is observed that these studies are carried out with different perspectives on traffic. For instance, [9] shows that artificial neural networks and randomized algorithms of stochastic approximation allow building systems for traffic light operation control that take into account various non-linear stochastic relations between locally observed network loads. Another approach was proposed by Safadi and Haddad in [10]. They presented an optimal analytical solution coupling both traffic routing and signal control in a continuous-time model for simple traffic networks. Another analytical solution proposed in [11] is a two-stage model based on period-dependent area traffic signal control. From a different perspective, for intelligent traffic light control multi-agent broad reinforcement learning was used in [12]. For multi-intersection traffic signal control, a deep reinforcement learning-based cooperative approach was presented in [13]. In [14], introduced a traffic light scheduling algorithm called SmartLight that controls the competing traffic flows at the road intersections.

Heuristic algorithms come to the fore with their applicability in optimization processes and traffic problems. For example, in [15] Tong et al. compared two different heuristics in a simulation environment. Using a new hybrid algorithm, the authors carried out the study on a test road network. Abdalhaq et al. examined the effects of the Genetic algorithm, Tabu Search algorithm (TS), Particle Swarm Optimization and Stochastic Approach algorithms on a traffic model in the SUMO simulation program in [16]. Testing heuristics in different simulation environments, Gabriel et al. [17] examined the effect of model-based heuristics on traffic travel problems. The authors, who sought solutions with different heuristic approaches to solving nonlinear problems, stated the usability and efficiency of the algorithms [18] [19]. Akgüngör et al., on the other hand, aimed to develop heuristic approaches and find the best travel time for scenarios with high traffic density in [20].

As can be understood from the literature summary given above, a wide variety of approaches and solutions have been presented in traffic optimization. In this study, a heuristic algorithm is used to optimize traffic light durations on a test traffic road network in a SUMO simulation environment. Among the heuristic algorithms, the DE algorithm, which stands out in terms of high performance and stable solution generation, was preferred. By integrating DE with SUMO, optimizing has been carried out by avoiding the drawbacks of multi-individual (swarm) heuristics, focusing on operating with only one individual, which is unusual for DE. The experimental results obtained were compared with those obtained in multi-individual operations.

2. Softwares and Methods Used in the Study

In this section, the programming languages, heuristic algorithm methods and additional programs used in the study are given.

2.1. Auxiliary softwares

The auxiliary softwares used within the scope of the study are briefly described below and their intended use is expressed.

a) Programming language: The Python programming language, which can be easily integrated with different programs and environments, stands out with its compilability and simple syntax compared to other languages.

b) Extensible markup language (XML): It is a language that is generally used for data exchange and has a hierarchical tree structure. XML markup language is also used in the SUMO program structure, and certain XML files are processed with data transfer to enable simulation. In this study, XML markup language is used to operate the simulation program and integrate the heuristic approach into the simulation while the optimization process is run.

c) Operating Systems: Analysis processes were carried out under the Windows operating system. It is widely used as the main operating system in our computers where code editor programs and SUMO simulation programs are installed.

The SUMO simulation program can be used on different operating systems. The main operating system was determined as Windows, but the Linux operating system was also used because the SUMO program was easier and faster to obtain data in the Linux operating system for obtaining the result data.

d) Source Code Editor: Visual Studio Code was used as a code editor program to compile Python programming language, edit XML markup language codes and process the obtained data. It has been used as a code editing environment for this study due to its easy-to-use and colorful interface.

e) Simulation of Urban Mobility (SUMO): SUMO is an open-source, free simulation environment for small or large-scale traffic systems. Developed by members of the German Aerospace Center, SUMO was released in 2001. SUMO is an open-source space-continuous road traffic simulator commonly used for testing vehicular networks [21] SUMO allows one to obtain outputs visually and provides analysis by creating the output of an XML file. In this study, real-time traffic network modeling was done by exchanging data with XML files. SUMO can automatically model country and city road networks with the help of Google Maps and it also allows to create different traffic scenarios manually. The most important reason why it was chosen as a simulation program in this study is that it can be easily integrated with other software languages and allows to reach results easily close to reality.

2.2. Heuristic method and SUMO simulation for a benchmark road network

Differential Evolution (DE) algorithm, which is a swarm-based heuristic approach, has been used to optimize traffic signal durations. The DE algorithm used in the solution of nonlinear problems has been determined as the heuristic approach because it is stable and easy to code. The algorithm discovered by Storn and Price in 1996 maintains its popularity today and is used in many researches. In this study, it was used to determine the best light durations by running simulations with different numbers of individuals.

Developed by Allsop and Charlesworth in 1977, the road network is a test network used by researchers to aim to get the best travel time by passing specific routes to vehicles. The road network used in many studies in the literature was determined as a benchmark and simulated in the SUMO program.

The Allsop and Charlesworth road network has a total of 7 start and end points, 6 traffic light intersections, 23 road link indicators and 14 green light duration variables. In Figure 1, the image of the road network modeled in the SUMO environment is given. Numbered arrows correspond to lanes in which vehicles can move. The points starting with the letter A and progressing to the letter G represent the starting and destination points of vehicles.

The right of way given to vehicles for one or more lanes in traffic is called phase. There are 14 phases in the Allsop and Charlesworth test road network. Phase arrangements in the SUMO program are made with the help of the "*Net.Edit*" program, and sample phase arrangements for an intersection are given in Figure 2.

In the road network given in Figure 1, the right-of-way matrix for the indicated numbered arrows is given in Table 1. For example, at junction 1, the right of way is given to lanes 1 and 16 in the first phase. In the second phase, there is a right of way for lanes 1, 2 and 19. Likewise, there are 3 phases for junction 4, for example. In the first phase, the transition exists for routes 5, 11 and 12. There is a right of way for lanes 10 and 12 in the 2nd phase and lanes 5, 6 and 13 in the 3rd phase.

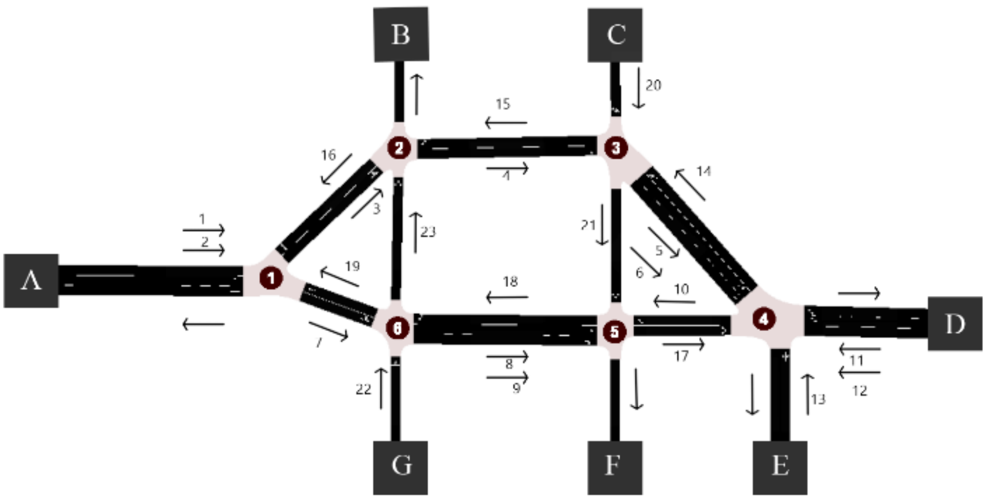

Figure 1. Allsop and Charlesworth road network modeled in SUMO environment

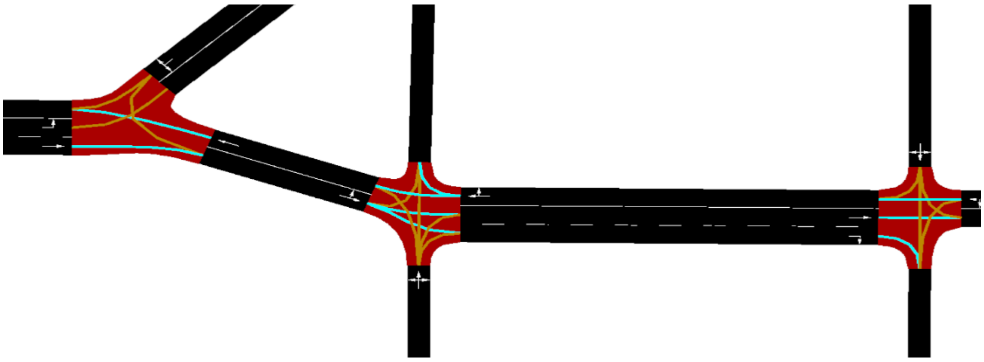

Figure 2. SUMO benchmark road network phase arrangements

Table 1. Road network phase matrix

Phases \ J#	1	2	3	4	5	6
Phase 1	1, 16	3, 15	20	5, 11, 12	8, 9	7, 18
Phase 2	1, 2, 19	23	4, 14	10, 12	8, 17	22
Phase 3	-	-	-	5, 6, 13	21	-

The sample traffic signal duration for the phases given in Table 1 is given in Table 2. According to the table, for example, a green signal time of 30 seconds is given in Phase 1 of traffic controller number 1. In phase 2, 20 seconds of green signal time is given for traffic controller number 1. The light duration (C) corresponds to the total green light duration.

Table 2. Example green signal duration matrix arranged by phase

Total Signal Duration (C)	Junction Number (i)	Phase 1 Green 1	Phase 2 Green 2	Phase 3 Green 3
50	1	30	20	-
70	2	20	50	-
80	3	30	50	-
120	4	40	40	40
110	5	20	40	50
70	6	30	40	-

2.3. Heuristic optimization of traffic signals

The first step of optimization signals of traffic networks defined in the previous subsections above is to determine the cost function used by the heuristic algorithm. The cost function used in the algorithm run throughout the simulation is given in Equation (1). The value of i in the equation shows the points where the vehicles starting the simulation from the T position can go as the destination point. The T position is given as the starting point, and the value of *J(T)* represents the value of the cost function. In this study, since it is aimed to reduce travel time, the individual quality calculation function given in Equation (1) was used.

$$J(T) = \sum_i \frac{(Time\ to\ reach\ T\ to\ i)(number\ of\ vehicles\ reaching\ i)}{(number\ of\ vehicles\ coming\ out\ of\ T)} \quad (1)$$

In order to obtain the best travel time on the road network, the population-based DE algorithm was run with different numbers of individuals and compared. The DE algorithm was operated with 1, 4, 6, 8 and 10 individuals in this study. For the problem-solving used in this study, all traffic signal phases were taken as a space dimension of the individual and a swarm consisting of 14 dimensional individuals was used. Each individual has phases of the traffic signal in size.

Due to its structure, the DE algorithm is operated by at least 4 individuals. In this study, apart from the conventional method, algorithmic calculations were carried out in the space dimension of a single individual. In the algorithm, 14-dimensional a single individual whose elements are the green light duration for each phase is used. Each element of the individual is used to generate a candidate individually, and the pseudo-code of the algorithm we used is given in Algorithm 1.

Individuals consisting of candidate traffic signal durations obtained with the running DE algorithm were subjected to balancing transactions in order to get meaningful values for the real world. Applicable values are obtained by proportioning very high signal times or very low signal times with the balancing process. Limiting conditions are given in Equation 2. According to the equation, *Cmax* corresponds to the sum of the maximum green and red signal duration, *Cmin* corresponds to the minimum total cycle value, *Qmin* corresponds to the minimum green light duration, *Qmax* corresponds to the maximum green signal duration, and *Q* corresponds to the green signal duration.

$$\left.\begin{array}{c} Cmax \leq 120 \\ Cmin \geq 25 \\ Qmin \geq 8 \\ Qmax < Cmax \\ Qmin < Q < Cmax \end{array}\right\} \quad (2)$$

In Figure 3, the flow chart showing the balancing transaction steps of the candidate individual obtained with the heuristic algorithm operated is given.

Optimization process was operated after integration of SUMO and DE algorithm. SUMO consists of three main files and uses that files created with XML tree structure [22]. In this study, Python file and SUMO XML files are interactivated with each others in order to integrate the SUMO program and DE algorithm as given in Figure 4. The result values obtained by running SUMO simulation at each algorithm step are sent to be used in the heuristic algorithm. In Figure 4, the working diagram of the SUMO files and the Python file in which the heuristic algorithm is implemented is given. According to the figure, "*yol.rou.xml*" containing vehicle information and "*yol.net.xml*" containing traffic signal durations were used for updating operations. The "*result.xml*" file is used for obtaining meaningful data to be used in the cost function, which outputs the SUMO simulation program.

Generate randomly initial individual elements in the interval of [Q_{min}, C_{max}]
Balance random assigned individual is balanced based on limitation of C_{max}, Q_{max}, C_{min} and Q_{min}
Set mutation factor $F \in [0,2]$, crossover rate $CR \in (0,1)$
Do (Main Loop)
Equalize candidate individual (U_{light}) and the main individual (X_{light})
For each x_i element of a single individual ($x_i \in X_{light}$)
Generate 3 random integers ($r_1, r_2, r_3 \in$ [1,D] and $r_1 \neq r_2 \neq r_3 \neq i$)
Generate a random integer $j_{rand} \in [1, D]$
$u_i \in Ulight$

$$u_i = \begin{cases} x_{r1} + F(x_{r2} - x_{r3}) & \text{if } (rand \leq CR \vee i = j_{rand} \\ x_i & \text{otherwise} \end{cases}$$

Balance Candidate individual is balanced based on limitation of C_{max}, Q_{max}, C_{min} and Q_{min}
End For
Calculate: Balanced U_{light} is sent to cost function and calculate travel time
If candidate U_{light} is better than X_{light}
$X_{light} = U_{light}$
End If
Until: Stop criterion is met
Solution: The last individual found will be the solution to the problem.

Algorithm 1. Pseudo-code of DE algorithm run with a single individual

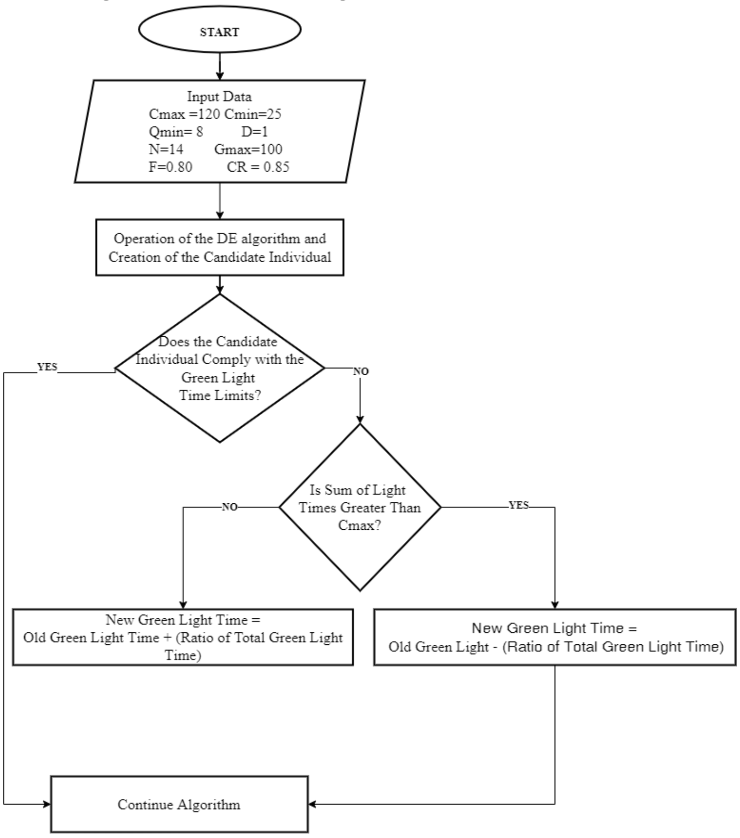

Figure 3. Transaction steps for balancing the traffic signal times

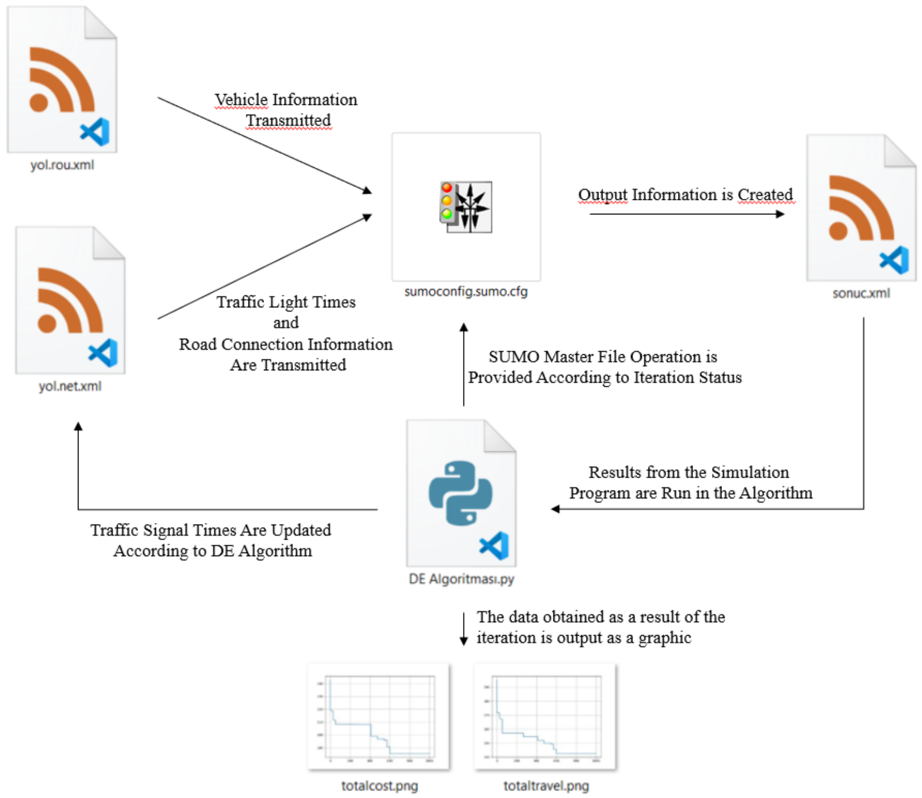

Figure 4. Integration scheme of SUMO and the heuristic approach

3. Experimental Results and Discussions

In this section, the performances before and after operated the algorithm are examined by applying the methods given above to the modeled benchmark road network. The optimized signal durations are examined both among themselves and with the pre-optimization data.

For the CR and F parameters, which are the basic parameters used in the DE algorithm, the CR = 0.85 and F = 0.80 values specified in [23] and suitable for the test road network were used. The DE algorithm was operated with 1, 4, 6, 8 and 10 individuals in this study. In an individual, the green signal duration of each phase was taken as an element as a space dimension of the individual. Hence, a swarm consisting of 14-dimensional individuals was used.

In Table 3, the number of vehicles in the traffic road network and the starting-arrival matrix of these vehicle numbers are given for each swarm size (1, 4, 6, 8 and 10). The initial traffic signal durations used on the benchmark road for each run of the approach proposed in this paper are given in Table 4.

Table 3. Starting-arrival matrix of vehicles used in the benchmark road network

Dest. / *Start*	A	B	D	E	F	Total
A	0	250	700	30	200	1180
C	40	20	200	130	900	1290
D	400	250	0	0	100	750
E	300	130	0	0	20	450
G	550	450	170	60	20	1250

Table 4. Traffic signal durations before optimization

Total Light Durations C(s)	Traffic Light Number (i)	Phase 1 Green 1	Phase 2 Green 2	Phase 3 Green 3
100	1	50	50	-
100	2	50	50	-
100	3	50	50	-
120	4	40	40	40
120	5	40	40	40
100	6	50	50	-

In Table 5, the simulation results obtained with the signal durations in Table 4 and the number of vehicles in Table 3 are given in [23]. The resulting total travel time is 198.85 minutes. It is aimed to optimize the average vehicle arrival times based on the starting points given in Table 5.

Table 5. Average arrival times in minute before the optimization according to starting points

Starting Points	A	C	D	E	G	Total Time
Average Arrival Time	80,22	44,35	18,13	30,34	25,81	198,85

The optimized traffic signal durations obtained after 1000 iterations of the heuristic approach applied to the simulation model with swarm sizes of 1, 4, 6, 8 and 10 are given totally in Table 6. In each step of the DE algorithm, candidate individual balancing process and constraints were applied and real-world data were obtained. When the traffic signal times in Table 6 and the number of vehicles in Table 3 are used, the average arrival times of the vehicles are given in Table 7.

Table 6. Optimized traffic signal durations

Total Light Durations C(s)	Traffic Signal Number (i)	Phase 1 Green 1	Phase 2 Green 2	Phase 3 Green 3
With single individual/Swarm size=1				
67,510	1	33,51	34,00	-
71,880	2	48,82	23,06	-
67,670	3	35,71	31,96	-
114,810	4	40,00	34,81	40,00
116,970	5	42,54	45,63	28,80
67,560	6	46,07	21,49	-
With four individuals/Swarm size=4				
111.813	1	33,40	78,40	-
117,228	2	58,95	58,27	-
44	3	19,96	25,03	-
118,128	4	30,11	34,53	53,47
102,025	5	46,59	38,93	16,49
100,018	6	56,01	44	-
With six individuals/Swarm size=6				
115,281	1	44,65	70,62	-
76,531	2	42,40	34,12	-
114,386	3	46,29	68,09	-
120,000	4	38,28	43,63	38,07
116,537	5	42,82	44,69	29,02
91,017	6	51,09	39,92	-
With eight individuals/Swarm size=8				
88,394	1	30,70	57,68	-
108,687	2	64,04	44,64	-
102,185	3	44,47	57,71	-
98,302	4	14,95	37,33	46,01
115,262	5	58,63	33,69	22,93
98,650	6	60,80	37,84	-

Table 7. (Cont.) Optimized traffic signal durations

Total Light Durations C(s)	Traffic Signal Number (i)	Phase 1 Green 1	Phase 2 Green 2	Phase 3 Green 3
With ten individuals/Swarm size=10				
116.906	1	16.73	100.17	-
108.885	2	50.33	58.54	-
87.877	3	45.70	42.17	-
109.260	4	29.92	47.93	31.39
75.428	5	43.09	22.04	10.29
68.000	6	40.13	27.86	-

The average travel times after the optimization are given in Table 7. According to the table, it is seen that better times are obtained at the traffic light durations determined by the heuristic optimization compared to times before optimization given in Table 5. The best values obtained in the table are written underlined, and the percent values given under each value show gain (↓) or loss (↑) from the time obtained according to values of the before optimization situation. According to Table 5, as an example, the average travel time for point C, which was 44.35 minutes before the optimization, decreased to 30.52 minutes with the signal durations determined by the algorithm operated with a single individual. This value shows that 31.18% of the travel time is saved. For vehicles starting from point C, an increase of 7% was determined for the algorithm operated with four individuals and 3% for the algorithm operated with eight individuals, resulting in a loss in travel time.

Table 8. Average travel times in minute using signal durations optimized

Number of individuals (Swarm size)	Starting Points					Total Average Arrival Time
	A	C	D	E	G	
1	48,84 ↓%39	30,52 ↓%31	14,64 ↓%19	17,34 ↓%42	23,97 ↓%7	135,31 ↓%32
4	70,54 ↓%12	47,50 ↑%7	14,73 ↓%19	17,95 ↓%41	21,33 ↓%17	172,05 ↓%13
6	70,57 ↓%12	36,16 ↓%18	13,37 ↓%26	17,79 ↓%41	25,18 ↓%2	163,07 ↓%18
8	67,36 ↓%16	45,69 ↑%3	11,61 ↓%36	11,73 ↓%61	18,77 ↓%27	155,16 ↓%22
10	57,48 ↓%28	43,47 ↓%2	14,46 ↓%20	17,58 ↓%42	31,21 ↑%21	164,20 ↓%17

As can be seen in Table 7, the optimization with the best travel time was achieved with a single individual, and the worst travel time was obtained with 4 individuals. It is seen that the results of the optimizations made with 6, 8 and 10 individuals are close to those obtained with 4 individuals on the basis of total travel time. For points A and C, the best results were obtained in a single-individual heuristic run. For points D, E and G, running with eight individuals gave the best results. While points D, E and G are narrower roads, points A and C are roads with wider lanes, and the number of individuals may show different effects according to road capacities.

In Figure 5, the instant traffic visuals corresponding to the 1.26 moment of the simulation done with the SUMO program using unoptimized signal durations are given. For the sake of comparison, the visual states of the simulation at the same simulation time for the two best cases in terms of the total average arrival times of the vehicles in Table 7 are given in Figure 6 and Figure 7, respectively. According to the pre-optimization traffic density visual given in Figure 5, when Figures 6-7 are examined after the optimization, it may be clearly seen that traffic density decreases. It has been determined that the proportional increase or decrease of the number of individuals does not increase or decrease the traffic density or indirectly travel time to a certain extent. In this context, it has been seen that the number of suitable individuals is among the parameters that should be carefully determined.

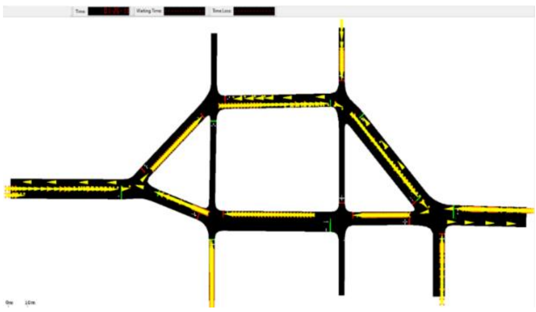

Figure 5. Traffic visual at the 1.26 moment of the simulation done with unoptimized traffic signal durations

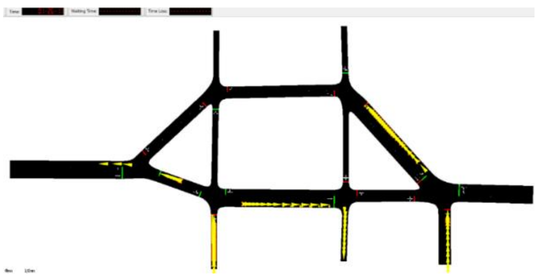

Figure 6. Traffic visual at the 1.26 moment of the simulation done with optimized traffic signal durations using only a single individual

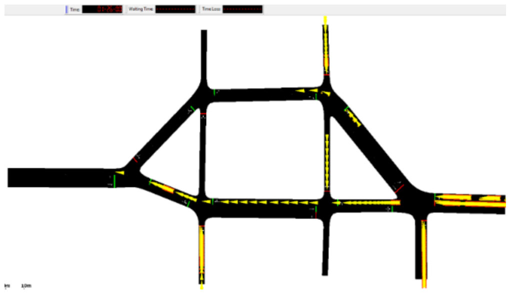

Figure 7. Traffic visual at the 1.26 moment of the simulation done with optimized traffic signal durations using a swarm of 8 individuals

In Figure 8, the training graph obtained as a result of the heuristic approach operated with different numbers of individuals is given. According to the graph, for example, there is a regular improvement for the algorithm run with a single individual and eight individuals. For the algorithm operated with four, six and ten individuals, no change was obtained after the first 10 iterations.

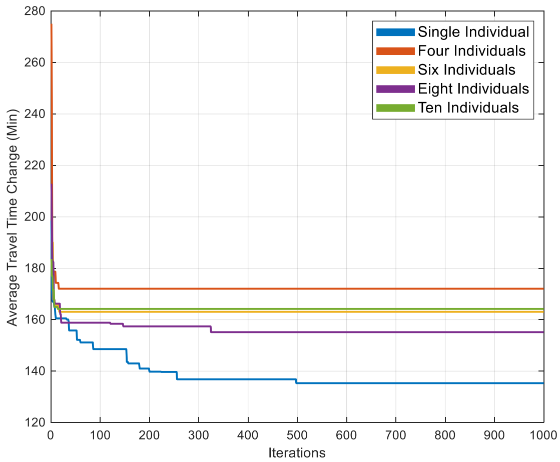

Figure 8. Training graph based on the number of individuals for the heuristic algorithm run with 1000 iterations

The average travel time of the vehicles leaving the starting points is given according to the number of individuals in Figure 9. According to the graph, for example, for vehicles starting from point A, it was seen that the time before optimization, which was 80.22 minutes, took the lowest value for a single individual. The first values in the graph where the number of individuals is 0 correspond to the values before the optimization.

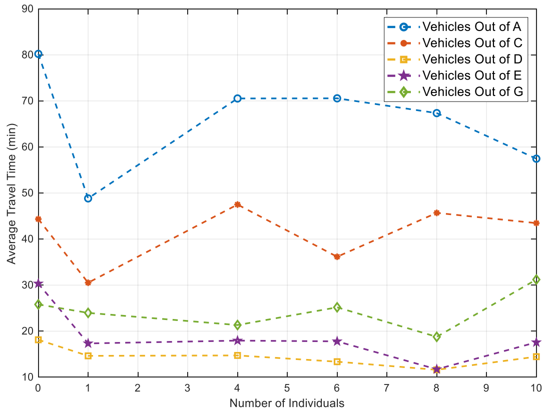

Figure 9. Change in the average travel time of vehicles leaving their starting points according to the number of individuals

In Figure 10, the average travel time bar graph is given according to the exit points of the vehicles that started their journey. According to the figure, for example, for point A, the best value of the average travel time is the algorithm run with a single individual colored orange, and the worst is the travel time before the optimization.

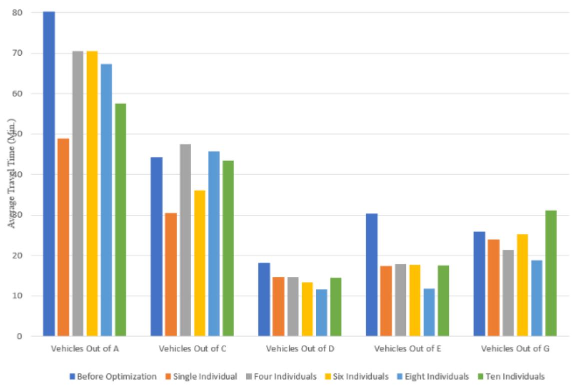

Figure 10. Average travel time bar graph by individual number of vehicles leaving their starting points

In Figure 11, the variation of the total average travel times depending on the number of individuals is given in the form of a line graph. According to the figure, the 0 point where the number of individuals is not present represents the travel time before the optimization. As the number of individual increase, the change in the average travel time changes in a fluctuating manner and it has been observed that a result is not obtained in proportion to the large or small number of individuals. It can be understood from this graph that the number of individuals is important for the optimization of the problem.

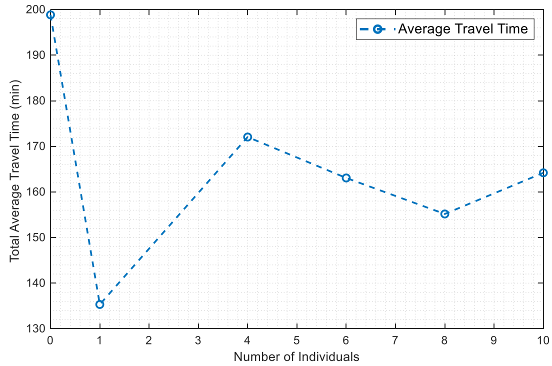

Figure 11. Variation of total average travel times depending on the number of individuals

In Figure 12, the completion time graph of the road network traffic signal durations optimization process, which is operated according to the number of individuals, is given. For example, when the algorithm operated with 4 individuals is used, the average completion time of an iteration is 2.02 minutes, and as a result of 1000 iterations, this time is calculated as 2020 minutes. When the algorithm operated with a single individual is used, it has been observed that the application of balancing processes in each dimension of the individual increases the completion time of the optimization process.

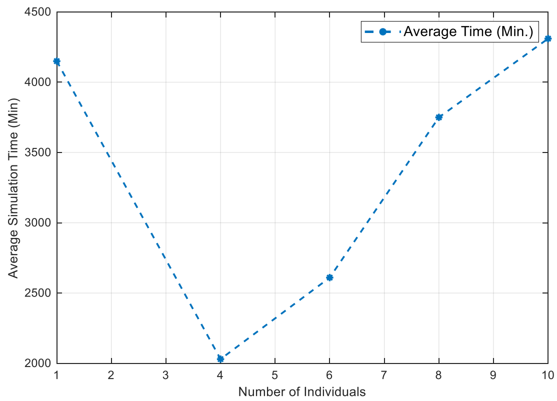

Figure 12. Completion time graph of the optimization process according to the number of individuals (1000 iterations)

4. Conclusion

With the study carried out, first of all, it has been shown that traffic light times can be optimized with a heuristic approach. Although the traffic optimization process is done in a simulation environment, it can take a long time. The operation of swarm-based heuristic algorithms with a large number of individuals, that is, with large swarm sizes unfortunately, increases this optimization process dramatically. Based on this determination, in this study, we focused on operating a heuristic algorithm with a single individual in order to reduce the optimization process. It is very unusual to work with a single individual for the DE algorithm, which is one of the heuristic algorithms that stands out with its easy applicability, performance and stability, and was deliberately chosen to be used in this study due to these features. Because the algorithm has a structure to work with at least 4 individuals. The most valuable contribution of this study is to demonstrate the usability of DE for optimization by running it with only one individual. Another contribution is to examine the effect of the number of individuals on the optimization with the heuristic approach based on the optimal traffic light duration determination problem studied here. It has been shown that the number of individuals is a very effective parameter in the optimization processes in heuristic algorithms and directly affects the optimization process. Based on the proportional change in the number of individuals, it did not affect the travel times proportionally. This shows us that too many individuals or too few individuals are not better and that it should be subjected to the optimization process for individuals as well as parameter optimization by making different experiments to determine the best number of individuals in each problem.

As a result of the study, positive results were obtained by gaining travel time according to the traffic scenario before the optimization in all the number of individuals. It has been observed that the difference in the number of individuals shows differences in the travel times of the main roads and side roads. It has been determined that the fixed-term traffic lights have lost their adequacy today and that supporting them with smart systems will be beneficial for everyone in the traffic network. In this context, it is recommended for future studies to adapt the optimized traffic signal times with smart systems, as was done in this study.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

For his support in understanding the traffic network and related concepts used in this study, the authors would like to thank Dr. Hasan BOZKURT.

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