Optimization of passive transit signal priority for El-Raml tram, Alexandria, Egypt

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1. Abstract

Promoting public transit can be done at a reasonable cost using the tram system. However, the system's steady operation depends on the delay at signalized junctions. Transit signal priority (TSP) control has been investigated as a way to enhance system performance. To address this challenging issue, our work concentrates on passive TSP control for the Tram system. To minimize per capita delay, an optimization model is developed to coordinate signal offsets along the Tram Line's arteries. The results of our case study on the tram route in Alexandria, Egypt, suggest that passive TSP control could give trams priority while little affecting other traffic. Using a meta-heuristic algorithm and a genetic algorithm, we present a unique passive signal priority with average per-vehicle delay minimization as a goal. The mathematical optimization model is developed based on the Highway Capacity Manual (HCM2000). For the resultant optimal TSP, a set of restrictions has been established to indicate effectiveness and security. We compare the resulting cycle length and phasing timing in each junction using the "Pattern search algorithm," another effective optimization methodology, to show the effectiveness of the suggested approach. The results show that the objective function of the genetic algorithm and the pattern search algorithm is pretty much identical, also the tram headway, cycle lengths, and green time for each phase of the signalized intersection along the tram line will be presented in the study.

Keywords: Transit Signal Priority, Optimization, Genetic Algorithms, Pattern Search, Control Delay.

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2. Problem Statement

The issue raised in this investigation is the synchronization of traffic signals to produce a green wave band that allows for as much uninterrupted tram and vehicle progress along the tram corridor as possible, with the best cycle length and timing for each phase for all intersections that share the tram's right of way. Figure 1 shows the study area considered for the current study with 13 intersections, and there are two forms of the right of way at these intersections. The first is an exclusive right of way for trams at intersections (3,5,6,7,8,13), where trams operate on a fully separated and protected right of way (elevated structure). The second type of right of way for intersections is a shared right of way (1,2,4,9,10,11,12) the tram vehicles share the right of way with other traffic which requires solving conflicts between the tram and other traffic by using signal timing adjustments at these intersections.

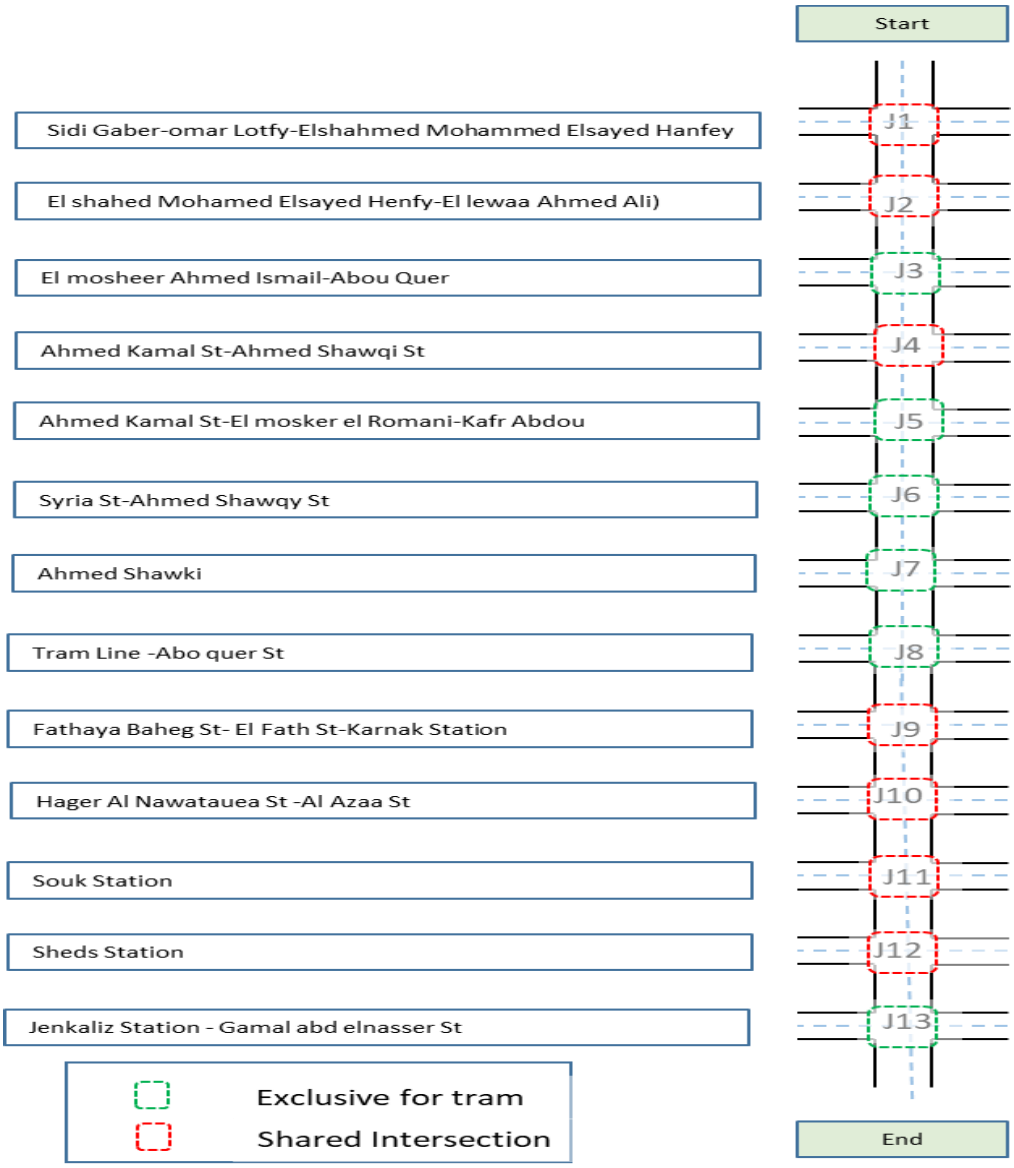

Figure 1: Study area

3. Traffic Signal Priority

Timetables could be determined for intersections with exclusive right of way for trams (3,5,6,7,8,13) without considering other traffic, but for intersections with shared right of way (1,2,4,9,10,11,12), a potential conflict between trams and other vehicles must be resolved, and typically the tram takes priority over traffic. tram signal priority comes in three types: active, passive, and adaptive techniques.[1]. The first type is the active signal priority which gives the tram a green traffic signal whenever it reaches the intersection[2].

a. Green extension: occurs when a tram is coming and the signal is green, but the remaining green time is not efficient for the tram to cross the intersection. In this case, a green extension action will be done.

b. Early green: occurs when the tram is coming near the end of the red phase early green action will be made to decrease the conflicting phase.
c. Phase insertion: occurs when the tram comes in the middle of the red phase, phase insertion action will be made.

However, active tram signal priority causes delays for other vehicles sharing the right-of-way with the tram, necessitating the installation of detectors ahead of the crossing to activate tram priority[3]. The second traffic signal control strategy is a passive signal priority, Passive techniques establish a predetermined timing that considers the arrival of the tram. They are beneficial when the tram arrival time is known[1]. The arrival of the tram can be handled by creating a coordinated traffic system that provides a green wave band for tram vehicles[4]. In synchronized systems, each of the signals must have the same cycle length. This is essential to make sure that the starting of green at the upstream and downstream junctions occurs at the same time [5]. therefore, the intersections (1,2,4,9,10,11,12) signals must have the same cycle length.

Using the passive signal priority will minimize the impact on other vehicles that share the right of way with the tram and also detectors are not required, the reliability of passive signal priority is determined by the performance of tram run-time between intersections. The last one is the adaptive signal priority which optimizes traffic timing according to real-time traffic volumes, It should be implemented in accordance with traffic states to optimize some general performance indicators, such as optimizing headway regularity[6], person delay [7], as well as various weighted combinations of schedule or person delay[8]. but it needs also to install detectors ahead of the intersection which results in heavy delays for other traffic.

4. Data Description

4.1Traffic Volume

A traffic survey was done to collect the traffic volumes in all intersections along the corridor of the tram, Figure 2 represents the peak hour volume of the intersection that shares the right of way with the tram.

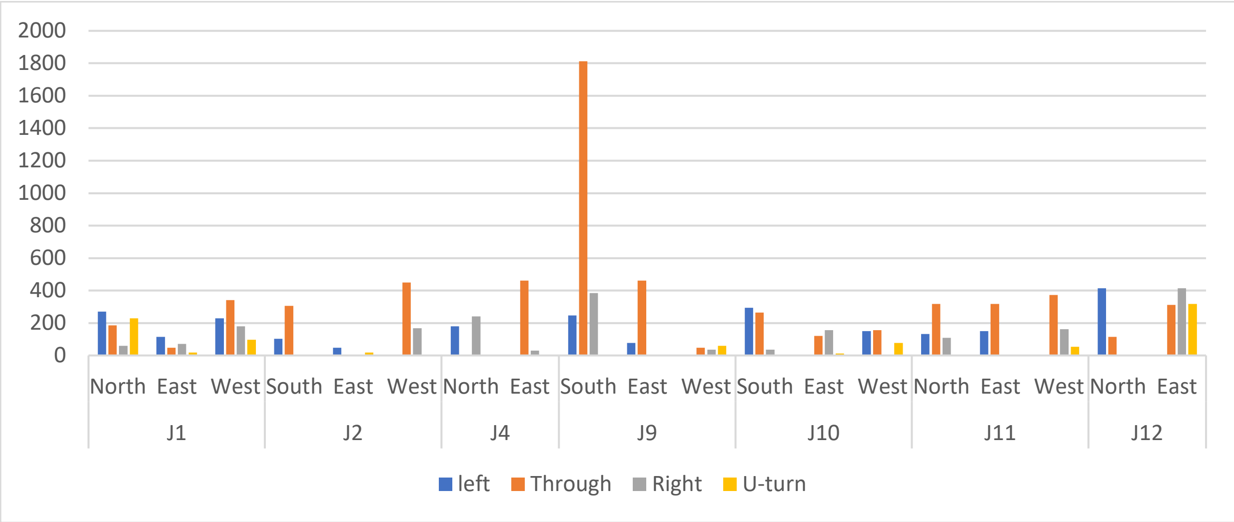

Figure 2 (Peak Hour Volume Veh/hour)

4.2Cycle Phasing

The phases of all intersections were created to make the tram cross the intersection without conflicting with other traffic vehicles. this can be achieved using two ways, first using a separate phase for the tram, and second making the tram cross the intersection with the parallel traffic that cannot cause conflict with the tramway, see Table 1.

Table 1 Intersections phasing sequence

Junction	Phase Sequence				Tram Phase
	One	Two	Three	Four	
J1					One
J2					Three
J3					Separate Phase
J9					Three
J10					Two
J11					Separate Phase
J12					Separate Phase

5. Mathematical model

5.1 Objective Function

The average control delay in seconds per vehicle is adopted as the optimization objective of the intersection delay, and the delay model of HCM 2000 will be used to estimate the control delay which will be produced due to using a traffic signal at the intersection [9] where:

$$d = d_1 * PF + d_2 + d_3 \tag{1}$$

Where, d is the average control delay in sec/veh, d_1 is the uniform delay in sec/veh, d_2 is the overflow delay in sec/veh, d_3 is the delay due to the preexisting queue in sec/veh and PF is the progression adjustment factor.

For all progressions factors (PF) is 1. d_3 for all lane groups is 0.00 sec/veh, indicating that there are no pre-queues at the start of the analysis period.

$$d_1 = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - [min(1, X) * \frac{g}{C}]} \tag{2}$$

$$d_2 = 900T[(X - 1) + \sqrt{(X - 1)^2 + \frac{8klX}{cT}}\ ] \tag{3}$$

where C is the cycle length in s, g is the effective green time for lane group in s, (X=v/c) is the ratio for the lane group, T is the length of the analysis period in hours, (k = 0.50) is the incremental delay factor controller settings and c is the capacity of lane group in veh/h.

5.2 Model Constraints

5.2.1 Cycle time

The summation of green time, yellow time, and all-red time for each phase should be with the same value of the cycle time[10].

$$\sum_{i=1}^{n}(g_i + yel_i + ar_i) = C \tag{4}$$

where *i* is the phase index, *ar* is the all-red time and *yel* is the yellow time, ar_i and yel_i is 2 sec and 4 sec for all phases

5.2.2 Phase green time

The minimal green time should be determined by the intersection design

$$g_i > g_{i-min}, \tag{5}$$

where, $g_{min} = 10\ s$

5.2.3 Cycle length

In synchronized systems, each of the cycle lengths must be equal. The is essential to make sure that the beginning of green happens at the same time as the beginning of green at the upstream and downstream intersections, and the cycle length is restricted to a range as shown.

$$C_{min} \leq C \leq C_{max} \tag{6}$$

where, $C_{min} = 15\ s$ and $C_{max} = 200\ \ s$

$$C_i = C_{i+1} = \cdots = C_m \tag{7}$$

5.2.4 Green time for tram phase

The minimal green time for the tram to cross the intersection

$$g_{tram-i} > g_{tram-i-min} \tag{8}$$

6. The proposed algorithm

The G.A is a search technique based 0n genetics and natural selection [11]. Several studies have used GA to study transportation networks such as transit network design problems considering variable demand [12], reduction of transfer time through scheduling changes[13], traffic control optimization [14], real-time dynamic TSP optimization [15], and adaptive bus TSP [16]. Genetic algorithms (G.As) are primarily search-based algorithms based on heredity notions and natural selection. GA is a subset of a much larger category of computation known as evolutionary computation. In G.As, we have a wide range of solutions for a particular problem. The solutions produced are subsequently exposed to recombination and mutation. (Similar to biological genetics), resulting in the birth of new offspring, and the process is repeated for several generations. Each individual is assigned a unique fitness value based on the value of its objective function, and individuals who are more fit have a higher chance of marrying and producing more fit offspring. This process ensures that fitter individuals and better solutions are developed in succeeding generations, which will continue until they reach the stopping criterion. Genetic algorithms are, to a large extent, probability-based in nature, however, they outperform local random search (which employs random solutions and is unable to discover optimal feasible answers) because it becomes more intricate and sophisticated as it incorporates historical data in nature.

The operation performs in G.A:

- Selection
- Crossover

• Mutation

6.1 Selection

A chromosome will be encoded with information related to a solution that it personifies. A binary string format is the most commonly utilized method of encoding. The chromosomes will then look like this.

Chromosome A	1	1	0	1	1	0	0	1	0	0	1	1	0	1	1	0
Chromosome B	1	1	0	1	1	1	1	0	0	0	0	1	1	1	1	0

Every one of the chromosomes may be depicted by a binary string. Each of the bit bits in the string is also responsible for certain aspects or standards of the solution.

6.2 Crossover

We can proceed to the crossover procedure once we have checked the stated coding to be used. Crossover operates on a subset of genes from parent chromosomes, resulting in the development of a new offspring. The simplest way to accomplish this is to choose a crossover point at random from the first parent point to this point. The graphic below depicts the crossover point cab:

Chromosome A	1	1	0	1	1	0	0	1	0	0	1	1	0	1	1	0
Chromosome B	1	1	0	1	1	1	1	0	0	0	0	1	1	1	1	0

Offspring A	1	1	0	1	1	1	1	0	0	0	0	1	1	1	1	0
Offspring B	1	1	0	1	1	0	0	1	0	0	1	1	0	1	1	0

There are numerous more ways to make the crossover, just as we may select many alternate crossover points. Crossover can be more sophisticated and detailed. It depends primarily on the encoding of chromosomes.

6.3 Mutation

After the crossover is generated, the following stage is mutation. The Mutation is designed to stop collapsing all solutions in the population into a local optimal of the solved problem. Offspring arises from crossing randomly modified by mutation technique. In binary encoding, we can swap some randomly selected bits from 1 to 0 or 0 to 1. Mutation might be ornamented as shown below:

Offspring A	1	1	0	1	1	1	1	0	0	0	0	1	1	1	1	0

Offspring B	1	1	0	1	1	0	0	1	0	0	1	1	0	1	1	0
Mutated Offspring A	1	1	0	1	1	1	1	0	0	0	0	1	1	1	1	0
Mutated Offspring B	1	1	0	1	1	0	0	1	0	0	1	1	0	1	1	0

As well as crossover the process of mutation depends on the encoding of chromosomes.

6.4 Genetic Algorithms Parameters

Crossover probability and mutation probability are the two essential parameters in a genetic algorithm.

6.4.1 Crossover probability

The number of times a crossover happens for chromosomes in one generation, the possibility that two chromosomes exchange some of their parts, hundred percent crossover rate means that all offspring are generated by crossover. If it is zero percent, then the full new generation of humans is to be perfectly duplicated from the older population, excluding those formed via the mutation process. The crossover rate is in the range of [0, 1].

6.4.2 Mutation probability

This probability regulates how several chromosomes should be altered in one generation, the mutation rate is in the range of [0, 1]. The objective of mutation is to keep the G.A from converging on local optimization, but if this happens frequently enough, the G.A is changed to a random search.

6.4.3 Population size

The population size represents the overall number of the population's inhabitants. Selection of population size is a sensitive problem, if the size of the population (search space) is limited, this suggests limited search space is accessible, and therefore it is possible to discover a local optimum. although, if the population size is very vast, the region of search is increased and the computational weight becomes great, therefore, the size of the population must be reasonable.

6.4.4 Number of generations

It refers to the total number of rounds before the ending. In certain circumstances, hundreds of loops are enough, but in other circumstances, we can need more, this relies on the problem's nature and complexity. Depending on the design of the GA, sometimes this option is not used, especially if the ending of the GA depends on stated criteria. Figure 3 shows the typical G.A.

Begin: The initial phase of any genetic algorithm is the generation of a random population of individuals. Each created individual is then represented as a chromosome in a series of L-length strings that correspond to the problem encoding. The phase concludes with the establishment of a random population in "genotype."

Fitness: The fitness value f (x) of each member of the present population is then computed. The evaluation method involves selecting individuals for mating based on their fitness values (parents) and the desired values of each.

New Population: To generate a new population, repeat steps 4, 5, and 6 up to completion.

Selection: The selection process denotes the chromosomes chosen for mating and reproduction, as well as the number of children produced by each chosen chromosome. The main purpose of the selection process is that "the better an individual is, the more likely it is to be a parent." In order to solve the optimization problem, several classic selection methods and user-specified selection mechanisms are used.

Crossover: The use of the selection procedure determines which parents are used in the crossover to create a new child. Crossover is accomplished by identifying a random location on the chromosome where the parents' components are exchanged. The crossover then generates a new offspring based on the exchange point chosen with the specified components of the parents.

Mutation: In most cases, the mutation occurs after crossover. This process applies alterations to one or more "genes" at random to produce new offspring, resulting in innovative adaptive solutions that avoid local optima.

Termination criteria: GA must finally come to a halt in order to announce the finest solution accessible. There are many termination conditions that are employed, including:

- When there has been no improvement in the population for a number of iterations.
- When we attain an absolute number of generations.
- When the objective function value has achieved a specified pre-defined value.

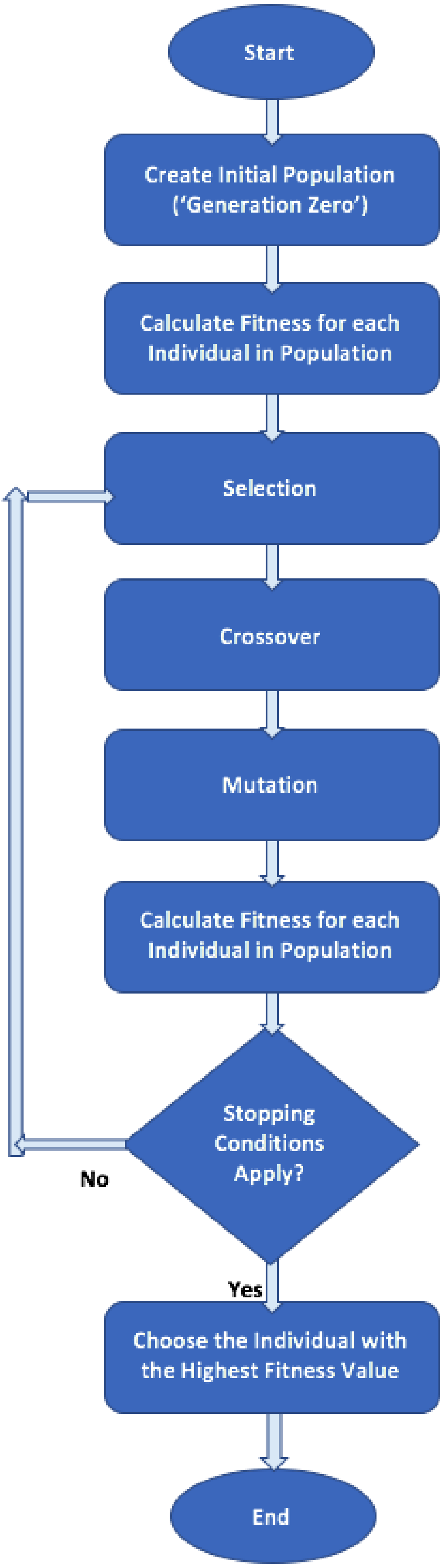
Start
Create Initial Population ('Generation Zero')
Calculate Fitness for each Individual in Population
Selection
Crossover
Mutation
Calculate Fitness for each Individual in Population
Stopping Conditions Apply?
No
Yes
Choose the Individual with the Highest Fitness Value
End

Figure 3 Genetic algorithm flowchart

In order to demonstrate the efficiency of the method proposed we use another efficient optimization algorithm "Pattern search algorithm" to compare the resulting cycle length and phasing timing in each junction.

7. Results and discussion

Figure 4,5 show convergence to the minimal objective function for the genetic algorithm and pattern search algorithm versus the number of iterations /generation. The objective function indicates the least average vehicle delay in sec/veh. through the tram corridor (7 intersections). Assessing the convergence trend from the plots (Figure 4,5), it is worth noticing that both the curves converge quickly to lower and lower values of the objective function. Both the curves' trends become flat forward once the objective function reaches a stable value as the number of iterations is increased. It can be noted from the plots that pattern search converges significantly faster than the genetic algorithm. However, the genetic algorithm solution quality is the same as the pattern search algorithm, the genetic algorithm converged to the objective function value of 42 sec/veh at about 400 population generation, while the pattern search reached a minimum objective value of 41 sec/veh at nearly 150 iterations.

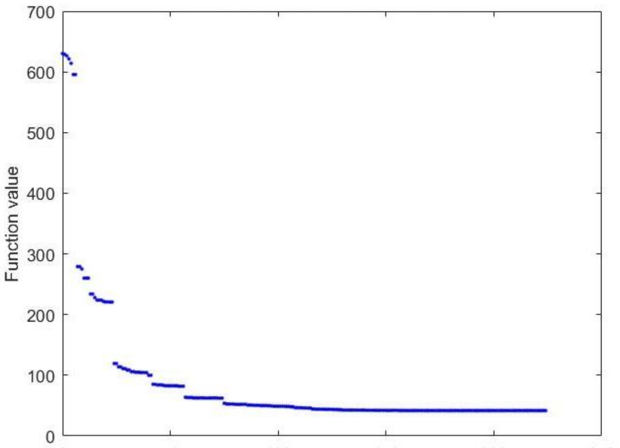

Figure 5: PS result

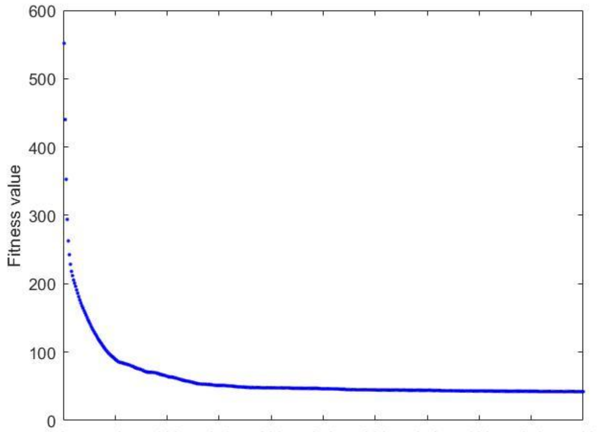

Figure 4: GA result

Table 2 Comparison results in the different algorithms. presents the optimized cycle lengths, corresponding green splits, and the average delay per vehicle in seconds for each intersection, to satisfy the synchronized systems requirements, all signals must have the same cycle length.

The is necessary to ensure that the beginning of green occurs at the same time relative to the green at the upstream and downstream intersections, therefore the genetic algorithm provides a 107-second cycle length against 118 seconds from the pattern search algorithm. To generate the green wave for the tram at all junctions, the tram headway must be a multiple of the traffic signal cycle length, so the tram headway must be a multiplication of 107 seconds according to the genetic algorithm or a multiple of 118 according to the pattern search algorithm.

Table 2 Comparison results in the different algorithms.

Junction	**Algorithm**	**The timing scheme**					**Per Vehicle Delay (s)**
		C	**g_1**	**g_2**	**g_3**	**g_4**	
J1	G.A	107	15	37	11	28	40
	Pattern Search	118	15	42	12	33	41
J2	G.A	107	32	23	40		33
	Pattern Search	118	20	28	58		37
J4	G.A	107	33	35	31		30
	Pattern Search	118	36	59	15		25
J9	G.A	107	57	28	10		55
	Pattern Search	118	65	31	10		49
J10	G.A	107	32	37	26		34
	Pattern Search	118	45	41	20		35
J11	G.A	107	22	23	35	15	50
	Pattern Search	118	25	27	39	15	51
J12	G.A	107	53	31	15		26

	Pattern Search	118	53	42	15		29

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