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Adaptive Dynamic Multiple Traffic Light Control System using Genetic Algorithm

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Abstract: In smart cities the traffic light control system is an old problem and new at the same time, and also it is a hard problem. So there are many researchers who addressed this problem in certain cases and due to the rapid development in technology, increases in vehicles numbers and speed and other causes of congestion at junctions which motivates the computer science researchers to develop dynamic system in order to manage different models of traffic lights to optimize and to coordinate the Traffic Signal Timing (TST). In this study, a dynamic program is proposed to simulate many of traffic lights models, which satisfy users requirement by defining parameters according to their need such as number of intersections **N**, number of phases (group light) **P** at each intersection, number of roads **R** connected to the intersections, and number of lanes movement **L** at each road. A Genetic Algorithm Traffic Signal Timing Management system (GATSTMS) is used to investigate the optimal solutions for cycle times, offset times and green times according to the sequence orders of a set of traffic lights. The fitness function is selected to minimizing the waiting time "delay" on the model. The proposed GATSTMS has the ability to handle and manage different models of traffic lights. We applied the GATSTMS on two models of traffic lights; the results showed that the GATSTMS produces good optimal solutions.

Keywords: Genetic algorithm, traffic light control system.

I. INTRODUCTION

With the growth of modern cities and the reliance of many of their populations on personal automobiles for the primary mode of transport, we need to use better traffic management systems[1] .

The importance of time for (passenger, teachers, managers, business men, …etc) is too valuable, so delay in junctions may cause lost worker productivity, or trade opportunities. In addition to economic impact, there are environmental pollution as CO_2, and black carbon emissions that cause a high temperature on ozone, serious illness[2]. In 2007 Urban Mobility Report estimates total annual cost of congestion for the 75 U.S. urban areas at 89.6 billion dollars, the value of 4.5 billion hours of delay and 6.9 billion gallons of excess fuel consumed[3]. To solve this problem, Most of traffic light control system studies have a static model in the number of intersections, where the shape of the flow was assumed to be the same for all phases, and the over flow to be constant, Also, the cycle time was assumed to be the same for all intersections, our main aim is to reduce the delay and optimize the flow ratio on junctions [4-8].

Some of researches fixed a cycle time for each intersection and change only on green split [6-9], also fixed the over flow The probability of enter main road equals 80%, the side road 20% (with except intersection of two main roads where the probabilities of the choice of the two target roads are equal)[6], when a cycle time is fixed, this will cause crowd in junctions, lost time, because in each intersection, the length of the overflow queue will grow from cycle to cycle[10]. The assumption in the older delay models is that the overflow queue is static, constant from cycle to cycle [7-9, 11]. The offset has proved that better results can be gained by using the coordinating control method when the distance between the neighboring intersections is not more than 800 meters[8].

In our countries most of traffic light control systems is pre-timed system. This type of systems corresponds to predicated traffic changes via preset changes on a time clock, Also there are different places which have congestion at junctions where study is require to reduce the delay time .In this study, we developed a dynamic program (GATSTMS) in order to adapt and coordinate most traffic lights models that have similar characteristics to our plan. To execute GATSTMS there are two files as inputs, the structure file which contains structure of traffic lights where the user can define the parameters such as number of intersections N, number of phases (group lights) P at each intersection, number of roads R connected to the intersections, and number of lanes movement L at each road, Also, the data file which contains the traffic lights data such as arrival, departure rate for each lane and vehicles distribution for each intermediate lane. In addition, the user can change phase shape and the sequence order. The GATSTMS can get the optimal solution for cycle times, green splits and offset times.

II. GENETIC ALGORITHM IN TRAFFIC SIGNAL OPTIMIZATION

The Genetic algorithm is a search technique whose the major idea is to solve optimization problems, so, the structure of genetic algorithm is the same as the structure of an evolution program and difference are hidden on the lower level[12]. Thus, To solve any problem as traffic lights using GA, there are four questions[13], if they are known; the problem will be essay to solve. These questions are:

What is the fitness function which used in traffic lights?

How is an individual represented?

How are individuals selected? And

How do individuals reproduce?

Each question from above questions will be illustrated in the next sections.

A. Chromosome representation:

In this model the chromosome is represented as binary digits with length Ch_L for each intersection and is calculated as follows.

Ch_L = (N + $\sum_{i=1}^{N}(G(i) + R_{intrmediate}^{i})$)*8 (1)

Chromosome length depends on a total number of intersections N, a number of lighting groups G(i) inside ith intersection and a number of intermediate roads $R_{intrmediate}^{i}$ connected to ith intersection. Each chromosome represents parameters Cycle Times (CT), Offset Times (FT) and Green split Times (GT). Each parameter multiplied by 8 because the highest value for CT is 256 seconds and also some of intersections may have one GT .

B. Fitness function:

The focus of this research is to minimize the delay, So the fitness function represents the average waiting time and is given by [8] :

$$wait = \sum_{k=1}^{K} \sum_{j=1}^{P} \sum_{i=1}^{N} \frac{1}{NV} \sum_{s=1}^{L} Delay_{i,j}^{s}(K) \qquad (2)$$

Where

Wait is the total average waiting time for all vehicles on the model during **K** cycle, **N** is number of intersections, **P** is number of phases of ith intersection, **L** is number of lanes of each road on ith intersection, **NV**: the number of vehicles per kth cycle**,** $\mathbf{Delay_{i,j}^{s}}$ is the waiting time for all vehicles of each lth of each ith from kth cycle.

This objective function must satisfy the following constraints:

$\min CT \leq CT \leq \max CT$,
$\min GT \leq GT \leq \max Gt$,
$0 \leq offset \leq CT$, and
$CT = \sum GT + Lost$
Lost= number of phases * IGP

After the GATSTMS obtains the solution which satisfy the previous constraints for each intersection, the evaluation algorithm coordinates these intersections to avoid queuing in intersections. The evaluation algorithm uses the sequence order and offset time. Thus, it may make small changes on some of genes of the CT and GT chromosome to satisfy the coordinating.

C. Select individual:

In this research, the Roulette wheel selection is used to rank the highest individuals to become parent for next generation, it is common method in literature and many researchers used it in their researches[6, 14]

D. Crossover and mutation:

Crossover operator produces a new chromosome (offspring) with a better characteristic than their parents. Its occurrence depends on the probability of crossover. The adapting crossover probability is around 85%[15].

Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of chromosomes to the next. Also mutation occurs during evolution according to a user-definable mutation probability, usually set fairly to low value, say the mutation probability is around 1%, [15].

The relation between population, crossover and mutation depends on population size, the small populations generally find good solutions quickly, but are often stuck on local optima. Larger populations are less likely to be caught by local optima, but generally take longer time to find good solutions[16].

III. PROPOSED MODEL

The model proposed is a general dynamic model, where number of intersections are **N** is in the range (2,N) , number of road **R** that connected to the desired intersection is in the range (1,4) (N=1,E=2,S=3, and W=4) see table 1, number of group lights **P** for each intersection are in the range (1,4), if group light is 1, this means there is one stage for the cycle in the desired intersection and so. In addition, the lanes movement type **L** for each road are in the range (1,3) as shown in figure1. We assume that each lane of the input road is provided with detector to detect the arrival vehicles, flow ratio dependence on the priority of the road, and average speed for each road will optimize the offset time .It is assumed that every vehicle is on the road of the lane that it wants.

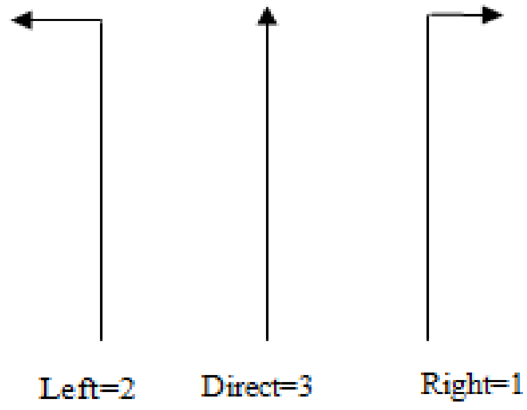


Figure1: Type of lanes for one road

Table 1: Directions lane movement for one intersection

lane mov / Direc	Right=1	Left=2	Direct=3
N=1	NE=11	NW=12	NS=13
E=2	ES=21	EN=22	EW=23
S=3	SW=31	SE=32	SN=33
W=4	WN=41	WS=42	WE=43

IV. SIMULATION

The proposed model, GATSTMS, is simulated using input from two files that contain the structure and the data of traffic lights. The structure file contains all parameters that needed to define the dynamic model, while the Data file contains the data needed for this model. We assume the Detector has detected flow per hour, then GATSTMS will update data file with arrival and departure for each lane.

In Figure 2 the modelled network consists of two intersections (C1 and C2) with three phases for C1, four phases for C2, also, each intersection consists of four roads (N, E, S and W).

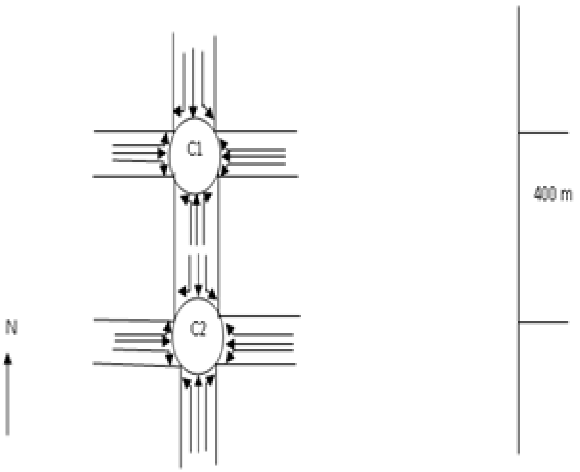


Figure 2: suggest network 1

Figure 3 shows the phases for intersection C1 and intersection C2, where the sequence order in the GATSTMS select phase 1 from intersection C1 and C2, then select phase 2 from intersection C1 and intersection C2,.. etc.

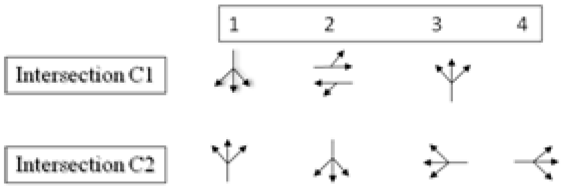
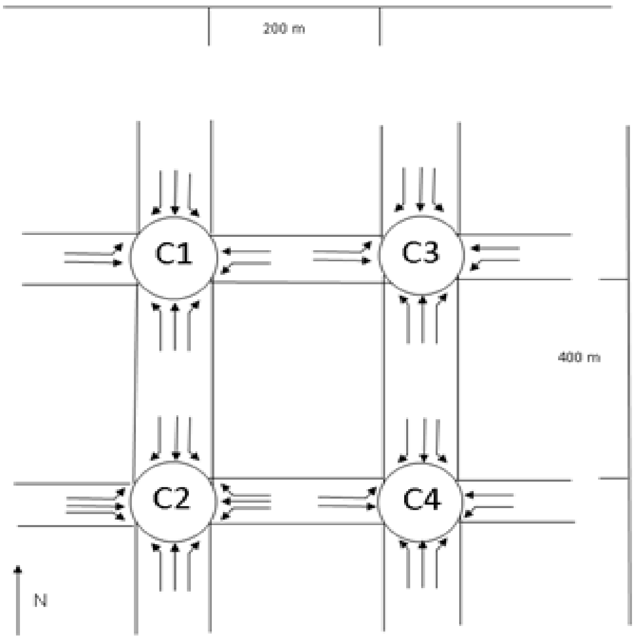


Figure3 : sequence order for network 1

Figure 4 shows another model of a network 2 which consist of four intersections (C1, C2, C3 and C4) and each intersection consist of 4 roads (N, E, S and W). Also, in this model, intersection one has three phases (group light), intersection two has four phases, intersection three has three phases, and intersection four has three phases.



Figur4: suggest network 2

Figure 5 show the phases for intersections C1, C2, C3 and C4, where the sequence order in the GATSTMS select phase 1 from C1, C2, C3and C4 . etc.

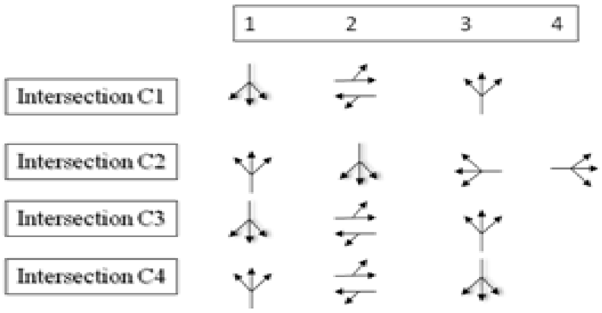


Figure5 : sequence order for network 2

V. RESULTS

The results shown from the simulation that the GATSTMS can get the optimal solution see figure 6,7,8,9. We test the network 1 under values 48<=CT<=120, 16<=GT <=40 for intersections C1 and C2. Figure 6 showed the results for the minimum of Total fitness (TF), minimum Fitness for intersection C1 (F1) and minimum fitness for intersection C2 (F2) for each generation based on data table and interaction of vehicles for each generation, where in first generation TF recorded was 833.5877's, F1 was 163.4693's and F2 was 670.1184's . In the second and third generation the GATSTMS get the optimal solution respectively (712.1425's, 652.8878's) for TF, (157.5795's, 145.7803's) for F1 and (554.563's, 507.1075's)for F2.

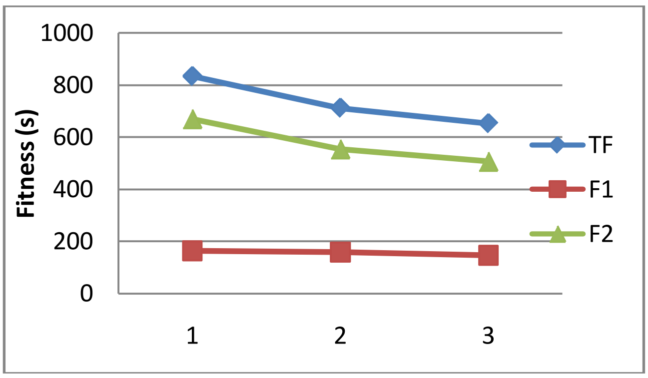


Figure 6: Fitness's VS generation

Figure 7 showed the relation between TF and optimal CT for intersection C1 and C2 for each generation, where the TF, CT1 and CT2 respectively (833.5877's, 92's and 120's), (712.1425's, 84's and 126's) and (652.8878's, 84's and 126's).

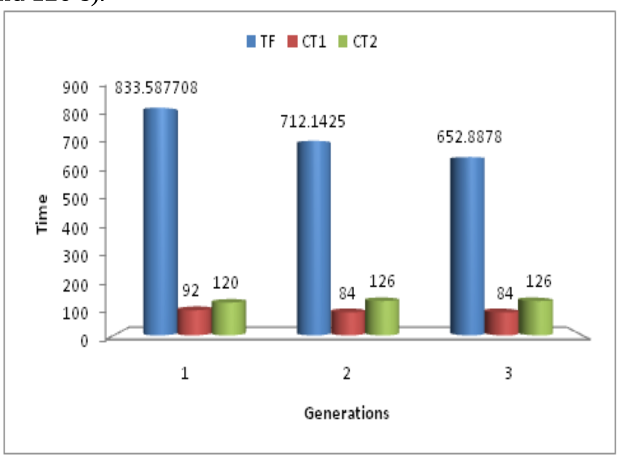


Figure 7: Fitness for optimal CT

Figure 8 show the optimal solution of intersection C1 for generation 1, 2 and 3. The result recorded for (CT, GT1, GT2 and GT3) respectively in generation 1 (92, 22, 34 and 36), in generation 2 (84, 26, 32 and 26), in generation 3 (84, 26, 32 and 26).

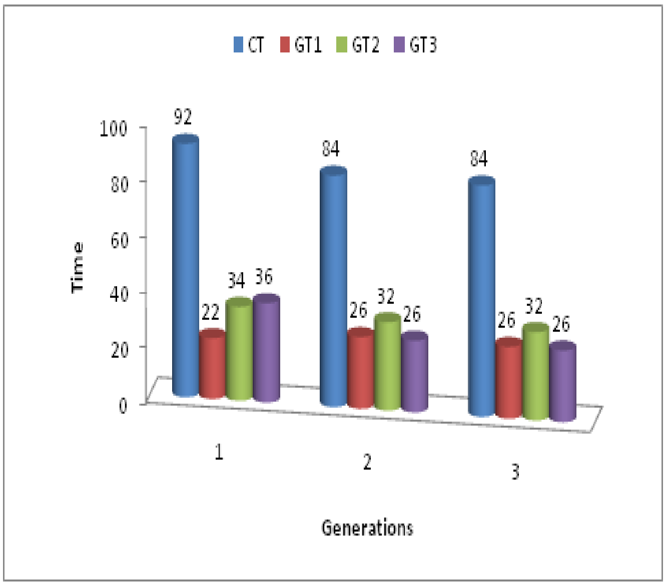


Figure 8 : optimal solutions for intersection C1

Figure 9 show the optimal solution of intersection C2 for generation 1, 2, 3 and 4. The result recorded for (CT, GT1, GT2, GT3 and GT4) respectively in generation 1 (120, 38, 25, 32 and 25), in generation 2 (126, 33, 32, 33 and 28), in generation 3 (126, 33, 32, 33 and 28).

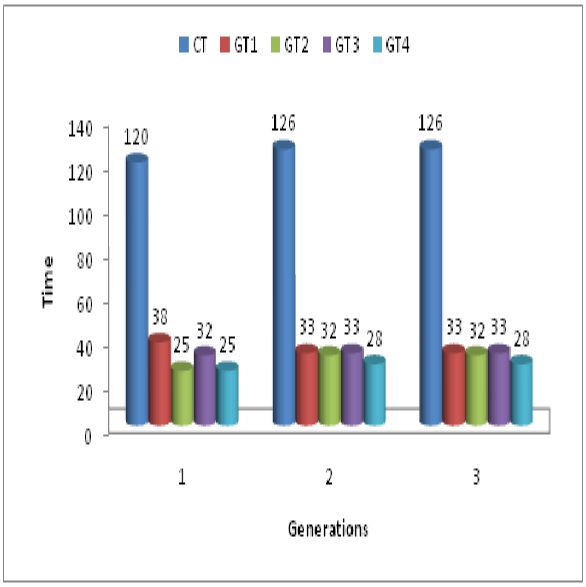


Figure 9 : optimal solutions for intersection C2

A. Comparison of the first model with fixed controller:

In this section, the authors compared the results obtained by GATSTMS with results obtained by [17]. The difficulty in obtaining a simple, easily computable expression for the average delay prompted researchers to look for approximations and bounds [17]. Delay formula used simulation to calibrate an approximate formula for computing average delay at a movement level which is given below:

$$d = \frac{CT(1-\frac{g}{CT})^2}{2(1-\frac{gx}{CT})} + \frac{x^2}{2q(1-x)} - 0.65(\frac{CT}{q^2})^{\frac{1}{3}}\, x^{2+5\frac{g}{CT}}, x < 1 \quad (3)$$

Where
d = average delay per vehicle (sec),
c = cycle length (sec),
g = effective green time (sec),
x = degree of saturation (flow to capacity ratio), and
q = arrival rate (veh/sec).

The first term of equation (3) is the expression for average delay assuming deterministic arrivals and a continuous approximation to the arrival and departure process[18]. The second term is the steady state delay for a queuing system with random arrivals and departures at constant intervals throughout the cycle[19]. The third term is an empirical correction term. A simplified version of the formula can be obtained by ignoring the third term and multiplying the result by 0.9[5]. This simplified form is often referred to as Webster's two-term delay formula.

The total intersection delay is obtained by multiplying the average delay for each movement by the corresponding arrival rate and summing over all movements, then, the total network delay is obtained by summing over all total intersections delay.

Table 2 showed the CT's for intersections C1 and C2 calculated by the formula as follow:

$$\mathrm{CT} = \frac{1.5\,LT+5}{1-\sum_{i=1}^{n}\mathrm{Yi}} \quad (4)$$

Where
LT: total lost time for cycle.
Yi: flow ratio for lane group i.
n: number of critical lane group.

Also, the table 2 shown the GT's proportion for intersections C1 and C2 that calculated from flow per phase over the total flow per junction, then depending on the CT's that obtained in equations 4. Last but not least, the GT (seconds) for each phase calculated fixedly from multiple the GT's proportion by CT's.

Table 2: compare CT's and GT's obtained

Data							Webster Formula		GATSTMS	
junction	phase	Lanes of phases	Flow/phase	Critical lanes	Total flow/junction	green proportion	green time	cycle time	green time	cycle time
junction 1	1	11, 12, and 13	3600	2400	12056	30%	18	60	22	92
junction1	2	21, 23, 41, and 43	5456	2828	12056	45%	27	60	34	92
junction1	3	31, 32, and 33	3000	2100	12056	25%	15	60	36	92
juncation2	1	31, 32, and 33	3720	3000	19047	19%	17	90	38	120
juncation2	2	11, 12, and 13	3540	2600	19047	19%	17	90	25	120
juncation2	3	41, 42, and 43	8118	5718	19047	43%	39	90	32	120
juncation2	4	21, 22, and 23	3669	2640	19047	19%	17	90	25	120

Table 3 showed the final results for average delay on each intersection C1 and C2 for the fixed control and GATSTMS have the same flow. We notice that the average delay in intersection C1 obtained by using the fixed control is higher than the average delay that obtained by using GATSTMS. However, in intersection C2 the average delay that obtained by using GATSTMS is higher than the average delay that obtained by using fixed control.

Clearly, the average delay in the fixed control gained the results depending on ratio as GT's proportion and degree saturation rate and so on while the average delay in the GATSTMS gained the results depend on the arrival and departure rate for each cycle.

The overall result shown that the average delay recorded (637.0573's, and 833.5877's) respectively for fixed control and GATSTMS.

Table 3: comparison average delay obtained

MOE	Fixed control		GATSTMS	
	Total flow Veh/hr	Avg delay (seconds)	Total flow Veh/hr	Avg delay (seconds)
Intersection C1	12056	199.1369	12056	163.4693
Intersection C2	19047	437.9204	19047	670.1184
Overall	31103	637.0573	31103	833.5877

We test the network 2 under values 48<=CT<=120, 16<=GT <=40 for intersections C1, C3 and C4, 60<=CT<=180, 15<=GT <=45 for intersection C2. Figure 10 showed the results for the minimum of Total fitness (TF), minimum Fitness for intersection C1 (F1), minimum fitness for intersection C2 (F2), minimum fitness for intersection C3 (F3) and minimum fitness for intersection C4 (F4) for each generation based on data table and interaction of vehicles for each generation, where in first generation TF recorded was 2275.659's, F1 was 379.4367's, F2 was 1129.3's, F3 was 263.0481's and F4 was 503.8039's. In the other generations the GATSTMS get the values for TF, F1, F2, F3 and F4 respectively (3399.385's, 2731.407's and 2707.973's) for TF, (531.3681's, 713.2933's and 704.5242's) for F1 and (1689.125's, 945.7847's and 944.9521's) for F2, (806.3294's, 790.024's and 777.106's) for F3 and (372.5623's, 282.5623's and 281.3906's) for F4.

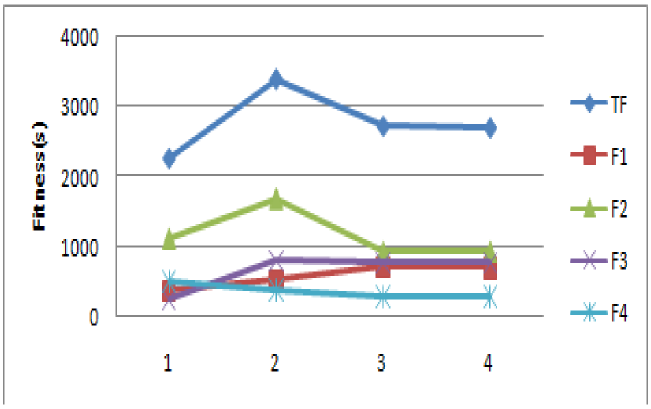


Figure 10: Fitness VS generations

Figure 11 show the relation between minimum TF for each generation and the optimal CT for each intersection. Where the optimal CT for intersection C1, C2, C3 and C4 at the generation 1 are respectively (95, 135, 80 and 97) recorded 2275.659's for the minimum TF in population. In the second generation the optimal CT are respectively (97, 130, 91 and 65) recorded for the minimum TF 3399.385's, in the third and forth generations the optimal CT respectively for C1, C2, C3 and C4 (89, 138, 105 and 117) and (99, 124, 91 and 65) recorded for the minimum TF (2731.407's and 2707.973's).

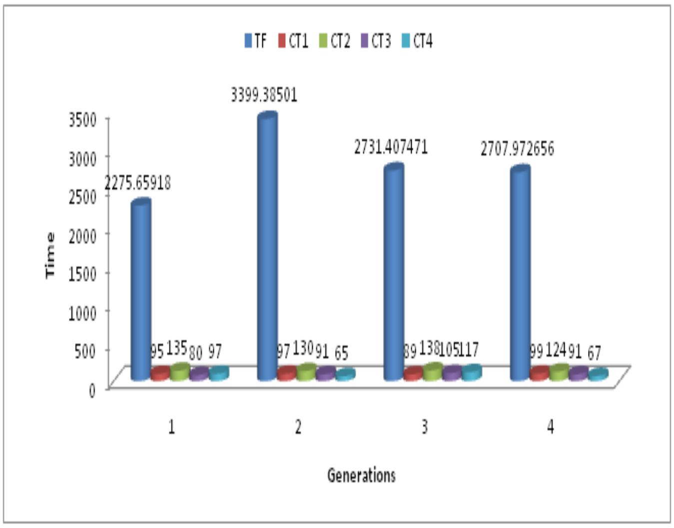


Figure 11: fitness for optimal CT

Figure 12 show the optimal solution of intersection C1 for generations 1, 2, 3 and 4. The result recorded for (CT, GT1, GT2 and GT3) respectively in generation 1 (95, 38, 36 and 21), in generation 2 (97, 39, 35 and 21), in generation 3 (89, 35, 35 and 19) and in generation 4 (99, 39, 37 and 23).

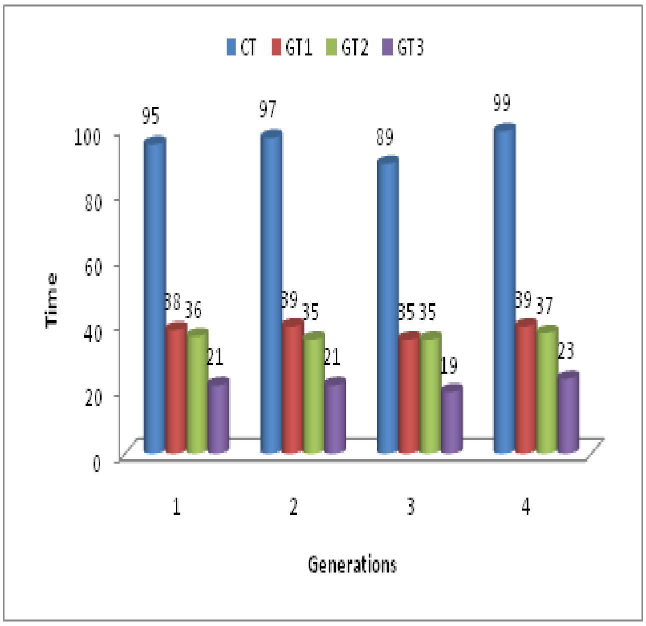


Figure 12 : optimal solutions for intersection C1

Figure 13 show the optimal solution of intersection C2 for generations 1, 2, 3 and 4. The result recorded for (CT, GT1, GT2, GT3 and GT4) respectively in generation 1 (135, 38, 39, 35 and 23), in generation 2 (130, 38, 36, 33 and 23), in generation 3 (138, 34, 38, 39 and 27) and in generation 4 (124, 34, 38, 39 and 27).

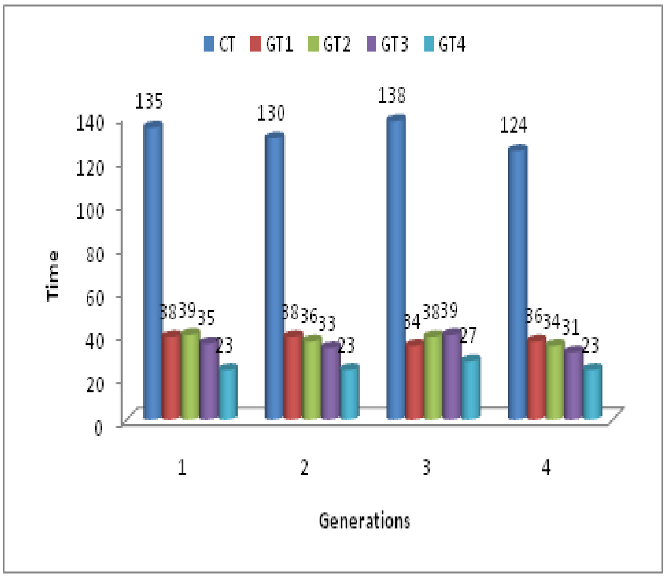


Figure 13 : optimal solutions for intersection C2

Figure 14 show the optimal solution of intersection C3 for generations 1, 2, 3 and 4. The result recorded for (CT, GT1, GT2 and GT3) respectively in generation 1 (80, 19, 23 and 38), in generation 2 (91, 19, 34 and 38), in generation 3 (105, 31, 36 and 38) and in generation 4 (91, 19, 34 and 38).

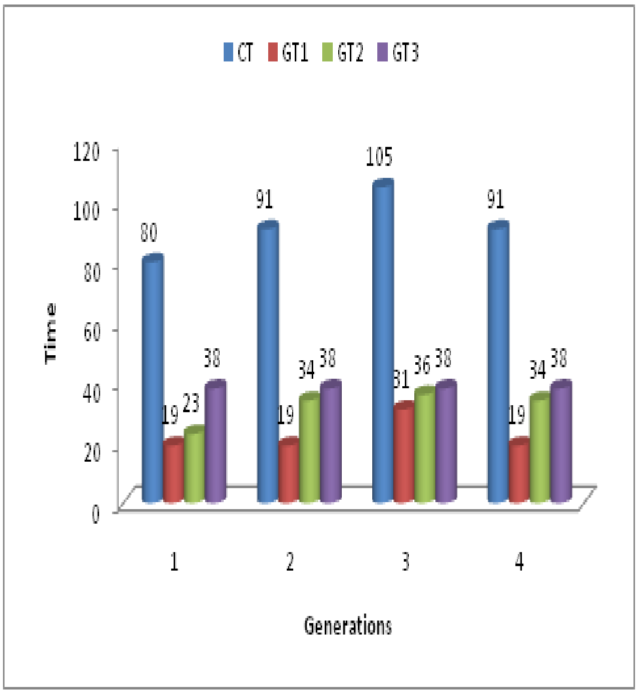


Figure 14 : optimal solutions for intersection C3

Figure 15 show the optimal solution of intersection C4 for generations 1, 2, 3 and 4. The result recorded for (CT, GT1, GT2 and GT3) respectively in generation 1 (97, 35, 28 and 34), in generation 2 (95, 32, 30 and 33), in generation 3 (107, 38, 32 and 37) and in generation 4 (97, 32, 33 and 37).

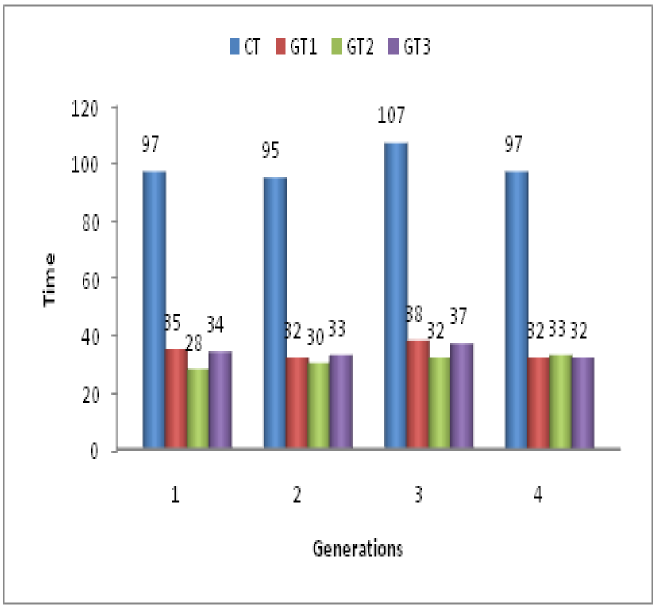


Figure 15 : optimal solutions for intersection C4

A. The Comparison of second model with fixed control:

Similarly, in this comparison we used the same equations that mentioned in the comparison of the first model.

Table 4 showed the CT's and GT's for each intersection that calculated using Webster formula and GATSTMS.

Table 4: comparison CT's and GT's obtained using Webster formula and GATSMS

Data							Webster Formula		GATSTMS	
Junction	phase	lanes of phases	Flow/phase	Critical lanes	Total flow/junction	green proportion	green time	cycle time	green time	cycle time
junction 1	1	11,12, and 13	3600	2400	12056	30%	18	60	22	95
Junction 1	2	21,23, 41, and 43	5456	2828	12056	45%	27	60	34	95
Junction 1	3	31,32, and 33	3000	2100	12056	25%	15	60	36	95
Junction 2	1	31,32, and 33	3720	3000	19047	19%	17	90	38	135
Junction 2	2	11,12, and 13	3540	2600	19047	19%	17	90	25	135
Junction 2	3	41,42, and 43	8118	5718	19047	43%	39	90	32	135
Junction 2	4	21,22, and 23	3669	2640	19047	19%	17	90	25	135
Junction 3	1	11,12, and 13	3600	2400	12056	30%	18	60	19	80
Junction 3	2	21,23, 41, and 43	5456	2828	12056	45%	27	60	23	80
Junction 3	3	31,32, and 33	3000	2100	12056	25%	15	60	38	80
Junction 4	1	31,32, and 33	3000	2100	12056	25%	15	60	35	97
Junction 4	2	21,23, 41, and 43	5456	2828	12056	45%	27	60	28	97
Junction 4	3	11,12, and 13	3600	2400	12056	30%	18	60	34	97

Table 5 showed the final results for average delay for each intersection C1, C2, C3, and C4 of the fixed control and GATSTMS that have the same flow. We noticed that the overall results shown the average delay recorded (1182.2312's, and 2275.659's) respectively for fixed control and GATSTMS. The reason for that the CT"s in the fixed control is less than the CT's in the GATSTMS , also the fixed control calculate the average delay depend on the ration while the GATSTMS calculate the average delay depend on the arrival and departure rat per seconds.

Table 5: comparison average delay obtained

MOE	Fixed control		GATSTMS	
	flow Veh/hr	Average delay (seconds)	flow Veh/hr	Avg delay (seconds)
Intersection C1	12056	199.1369	12056	379.4367
Intersection C2	19047	479.2469	19047	1129.3
Intersection C3	12056	207.2487	12056	263.048
Intersection C4	12056	296.5987	12056	503.804
Overall	31103	1182.2312	31103	2275.659

VI. CONCLUSION

This paper presented a dynamic model for most of the current traffic light control systems using genetic algorithm. In this work the user defines the structure of the traffic lights, and the GA program optimizes the traffic lights fluency, which can be achieved by finding the minimum delay in the entire system. The cycle time is defined at each intersection to enhance the fluency and to avoid the long queues in each intersection. One of the important conclusions of this work is presenting a more efficient GATSTMS algorithm that is suitable for wide range of different traffic models while considering a number of dynamic constraints. Thus, this paper presented the green splits such as dynamic as to control lanes movement of any road. the complexity increased in The proposed GATSTMS - when the number of intersections increase -.i.e. This back to the chromosome length that represent all parameters of intersections and many operators of genetic algorithm that used to model each intersection, and the process to evaluate and coordinate the dynamic model. In the second model the results showed that the intersection C2 that has 4 light group recorded high fitness compared with other intersections.

When we test the program under population size (100), the optimal solution showed at the first generation, because the gap between probability of the max fitness and probability of the average fitness was small than (0.007). We also test the program under population size (10), the optimal solution require more than one generation until the gap become very small between the maximum fitness and the average fitness or the number of generation reach 4.

From the comparison of the first model and second model we conclude that the fixed control recorded total average delay less than the total average delay in the GATSTMS, this back to many things: average delay calculated in Webster formula is approximation and continuous during the simulation where the GATSTMS calculate the average delay more accurately and discrete for each cycle. Average delay in Webster formula also depend on ratio like as degree saturation rate (x) that determine queuing increasing and decreasing where the GATSTMS monitors the queue in each cycle as numbers. Finally, as we conclude that the throughput in GATSTMS is better than the throughput in the fixed control, because the CT's and

GT's in the fixed control are fixed during the simulation but the GATSTMS have vary CT's and GT's during the simulation and the GT's in the GATSTMS is higher than GT's in the fixed control.

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