

Optimization of Traffic Flow Within an Urban Traffic Light Intersection with Genetic Algorithm

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Abstract—Traffic flow control optimization in the traffic light systems is studied for improvement in this paper. Traffic light systems are built to control the traffic flows at the intersections to ensure the fluency of traffic flow within the traffic network. The increasing traffic flows that cannot be supported by the current traffic light systems cause lengthen of queue length at the intersection. The effect of queue length, green time, cycle time and amber time in the traffic system is observed and studied through simulations. Longer green time will pass through more vehicles, but it will increase the cycle time at the same time which causes more vehicles to accumulate at the intersection during the waiting time. Genetic algorithm is introduced in this paper for the optimization of the traffic flow control as its ability to find the optimized solution in its self tuning process. Genetic algorithm taking current queue length as its input then it will output the optimized green time for the intersection. The result of Genetic algorithm is further improved with the introduced of the incoming traffic flow during red time of each phase.

Keywords-Genetic Algorithm, Traffic Control System, T-Junction, Traffic Flows

I. INTRODUCTION

The traffic flow conditions nowadays are getting more saturated compared to several years ago due to the obvious increasing of the on-road vehicles in Malaysia. New roads with more lanes are built to increase the capacity of the current traffic networks, but due to the fast development of most of the Malaysia's major city like, Kota Kinabalu, the land available for the construction of the new roads is limited. As construction of the new roads is no longer an option for the city planner, the optimization of the smoothness in the traffic network has become a difficult task.

Various traffic controls have been used at the current traffic network, from the simple traffic controller like road signs until the electronic traffic controller such as traffic lights [1]. In Kota Kinabalu, the common traffic controllers used in the traffic network are the road signs, traffic lights, and lastly road infrastructure such as, roundabout and flyovers. However, as the increase traffic flows in Kota Kinabalu has exceed the maximum capacity of the current traffic networks, traffic jam has occurred more often nowadays.

Under the condition of limited land available and the difficulty to rebuild the road infrastructure, one of the better solutions is to study and design a traffic light controller to optimize the traffic flow. Nowadays, most of the traffic light control systems still using predetermined setting which is not able to support the oversaturated traffic flow anymore [2].

The inefficiency of current traffic light system is contributed by the lack considerations of the real time traffic characteristic such as, queue length and traffic signals' duration into the traffic control. The incoming traffic flow during the red time also taken in as a consideration for the traffic control simulated in this paper. Genetic algorithm is introduced in this paper due to its mechanism of natural genetics that able to locate the near-optimum solutions rapidly.

II. TRAFFIC CHARACTERISTIC

A. Intersection

The traffic control system in this project is observed and investigated at a single intersection. In every junction or intersection, there will be ways of traffic flows which are called, "Phase" [1]. In this junction, there are 3 phases of traffic flows, which is shown in the arrows of Fig. 1.

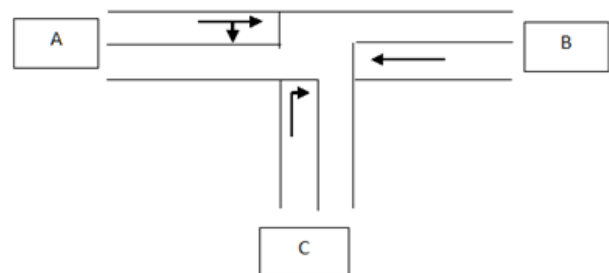


Figure 1. T-Junction with 3 Traffic Phase

B. Traffic Lights

Traffic lights are designed to control and optimize the traffic flow at the intersection by allowing only a certain phase of traffic flow to pass through the intersection at a

time. The phases get the permissions in turn, so that the smoothness of traffic flows within the intersection is secured and under control.

Three signals are given by the traffic lights to control the traffic flows, which are green, red and amber. Green signal is given when the phase of traffic flow gains the permission to pass through the intersection. Red is the sign of stoppage, meaning traffic flows are prohibited to pass through the intersection when red signal is given. Amber is the signal given between the red and green signal, indicating a warning to the traffic flow to slow down as the green signal is going to be ended.

The studies for the improvement in the traffic light control had been done over the years, since the primitive traffic light system failed to respond to the increasing traffic demands in the recent years. There are systems that using sensor to sense the incoming vehicle and use fuzzy logic to make decisions for extending the green light periods to let more vehicles pass through [3]. There are also studies about traffic control using wireless communications, where the vehicles send information to the nearby traffic control system, and then the system will optimize the traffic lights based on the information [4]. Genetic algorithm is also studied by others in traffic flow control. In the studies of genetic algorithm in traffic lights systems, travel time of vehicles over the road networks are the interest fields of studies which the genetic algorithm is used to optimize the flows of the networks [5].

In this paper, genetic algorithm also studied to optimize the cycle time and the traffic phase of the traffic lights systems, where the traffic flows of the traffic light systems are studied and Genetic algorithm is used to decide the phases, total green time of all traffic lights at the intersections, and the split of the traffic flows.

C. Intersection

Traffic flows control consists of several important characteristic and parameter, such as queue length, lost time, incoming traffic flow and cycle time.

Queue length is the total number of vehicles that line up in front of the intersection waiting to be given the permission for passing the intersection. The queue length is one of the performance indicators for the traffic control system. A weak traffic flow control will result a long queue length indicating the failure of the traffic flow control to let the large number of demand, while a short queue length represents that the traffic flow control able to let the most of the vehicles to pass through the intersection. The length of the queue will bring effect to other parameters such as the waiting time and travel time delay.

Travel time delay is the time needed by the vehicles to travel one point to another point. It is closely related by the waiting time of the vehicles in the traffic flow control. The long queue length will result in a longer waiting time for the vehicles and directly cause the travel time delay to be long. In this paper, the focus of the traffic flow control will be emphasized on the reducing of the queue length of the traffic flow in the intersection.

Other interested parameters are the cycle time and the lost time. Cycle time is the time for the traffic light signals to be circulated once after all of the phase having their turn in the green time. Lost time is the time lost between the interchange of the signals and also the time lost due the drivers' behaviors. Lost time may bring a significant impact upon the traffic flow control as it may increase with the number of interchanges between the signals. One of the main contributions to the lost time in the traffic flow control is the amber time. Amber time serves the purpose for differentiating the green time and red time; giving a period of time for the vehicles to aware and stop for the red time. But, it also reduces the efficiency of the green signals, as it already costs a period of time within a cycle of traffic light signals. Hence, reducing the number of cycle of traffic light signals by lengthen the cycle time is also one of the aim of this paper by using the genetic algorithm in the traffic flow control.

One more parameters that are involved in the study of this paper is the incoming traffic flow, as the incoming flow is the one which increasing the queue length and the demand of the green light in the traffic flow control. Especially during the red time, because the vehicles are not allow to be pass through during that particular time causing the queue length to keep increasing due to the incoming traffic flow. It is important that the traffic flow control is able to respond fast to the incoming traffic flow for a better optimization of the traffic flow within the intersection.

III. GENETIC ALGORITHM

Genetic Algorithm is a technique or a method to find the most optimum solutions for the problem through the processes of selection, reproduction, and mutations which are the concept adapted from the genetic evolution in the biology studies. The characteristic of the genetic algorithm to mimic the evolution theory of the nature allow it to reproduce a generation after another generation while eliminating the unfit solution. In genetic algorithm, the fittest solution or the optimum solution will survive throughout the processes in the end.

Solutions of the problems are represented by the chromosomes or gene within a population where the population is the area or boundary of the chromosomes or genes exists. Population in genetic algorithm means the set of chromosomes within a boundary of interests where the range and the number of the chromosomes can be determined. Fitness function is a function or the rule of the genetic algorithm to select the fit solution or gene. Every solution will be filtered by the fitness function and the fitness of each chromosome is determined or calculated. The fitness of every chromosome is then used for the ranking process.

Ranking is used to produce a list of the chromosomes according to their fitness. After that the rank will be used for the selection process which the fitter chromosomes will be selected and the unfit chromosomes will be filtered. The number of the chromosomes is maintained the same with the original population size. After the selection stage, the selected solution will go through another stage of process,

reproduction. In reproduction stage, the selected chromosomes will become the parents of the next generation. The new chromosomes produced are now the population of the new generation of genetic algorithm. Genetic algorithm will stop when the stopping criteria is reach. The stopping criteria can be the numbers of generations or the solutions reach the limit of the fitness functions [6].

A. Population of Chromosomes

Population which is the set of the chromosomes or solutions within the boundaries is needed to be determined. In the traffic flow control, the chromosomes are the green time of the traffic light system. So, the population boundaries are set to be above 0, as the green time cannot be smaller than the value 0. The number of chromosomes inside the population is also need to be decided, because the number of the solutions determines the speed of the optimization and the accuracy of the solution found. If too many solutions are generated in the population, then longer duration of time is needed to find the fittest optimization; but, if the number of the solutions is too little or small, the genetic algorithm may face the problem of finding the fittest optimizations. Therefore, a suitable number of chromosomes must be chosen carefully, as the traffic flow control needs both the speed and accuracy. In this traffic flow control, the number of the chromosomes is set to be 50 which mean that the genetic algorithm will generate 50 solutions in the population and the fittest solution will be found from the 50.

The initial range of the population also needed to be selected with careful observations. With the right initial population range, Genetic algorithm is able to select the best optimum point of interest. The initial population range is the range of the chromosomes for the first generated population for the genetic algorithm to start over with; the right range will save a lot of time for the genetic algorithm to find the desired or most optimum chromosomes. If the range is too small, it will affect the diversity of the chromosomes and then cause the genetic algorithm to miss out the real optimum point in the process and lock in a local optimum. Therefore, a suitable initial range is important for the traffic flow control, which is selected as 0 to 80 in this paper.

B. Generations and Reproductions

Another important field that must be considered is the number of generations that the genetic algorithm needs to be run. This is one of the stopping criteria for the Genetic algorithm, where the process will be stopped when the genetic algorithm already run for the number of generations that is determined. For this traffic flow control, the number of the genetic algorithms' generations is 100. This is chosen after a careful consideration in the effects of the number of generations upon the genetic algorithm. If too many generations are allowed to be run, then the genetic algorithm would suffer from a long computation time before it can stop. Another considerations, is when too little of generations are allowed to run, the genetic algorithm may not be as efficient as it should be, because genetic algorithm may not found the best chromosomes from the population.

Crossover fraction is the fraction of information from the parents or the chromosomes after the selection stage for the reproduction process. In the reproduction process, the chromosomes are selected in pairs to become the parents of the next generation of chromosomes. The crossover fraction determined how much fractions of a parent should pass to its children to produce a new chromosome. In this traffic flow control, the crossover fraction is determined as 0.8. This means that in a pair of parents, who is A and B will produce 2 children. The children are produced by taking the fraction of values or information from their parents. In this case, one of the children will inherit 0.8 of parent A and 0.2 of parent B and the other children will inherit 0.2 of parent A and 0.8 of parent B. As shown in (1),

$$\begin{aligned} X &= 0.2A + 0.8B \\ Y &= 0.8A + 0.2B \end{aligned} \quad (1)$$

Where X and Y is the new generation of inheritance.

C. Fitness Function

Fitness function is the rule or the equation to let the genetic algorithm selects the fit chromosomes from the population. Every chromosome in the population will be tested in the fitness function and the fitness function will produce a fitness value for them.

In this traffic flow control, the fitness function is actually a set of simple rules or codes. The fitness function of this traffic will take the queue length from all the three phases at that particular moment, and then it will test with all the chromosomes to optimize the green time by checking directly with the vehicle in queue of each phase.

Fitness limit is the other stopping criteria in this genetic algorithm where it is actually a target of the fitness function to reach. Fitness limit is actually the results of the fitness function, so once the best fitness value has reach the fitness limit, the genetic algorithm will stop the process and output the fittest chromosome. In this traffic flow control, the fitness limit is set to be 0 and once the chromosome fit in the fitness function and produces a fitness value of 0 or less, then the genetic algorithm will take that chromosome as the best fit optimizations.

D. Genetic Algorithm Simulation

The simulation of the genetic algorithm traffic flow control is run with amber time taken in as a consideration into the simulations to test the controller's response toward the actual situation. Genetic algorithm is found to be succeed in the optimization of the traffic lights system since the controller able to respond fast to reduce the vehicle in queue by generating a long period of green time for that phase.

Fig. 2 shows the output scope of the genetic algorithm mode. The first graph shows that the total vehicle coming into the traffic intersection over the 600 seconds of simulation while the third graph shows the total vehicles pass through the intersection during the simulation. From the fourth graph, the end results of the simulation shows a significant reduce in the vehicles in queue as the controller

successfully yielded only 7 vehicles in queue waiting for the next cycle time.

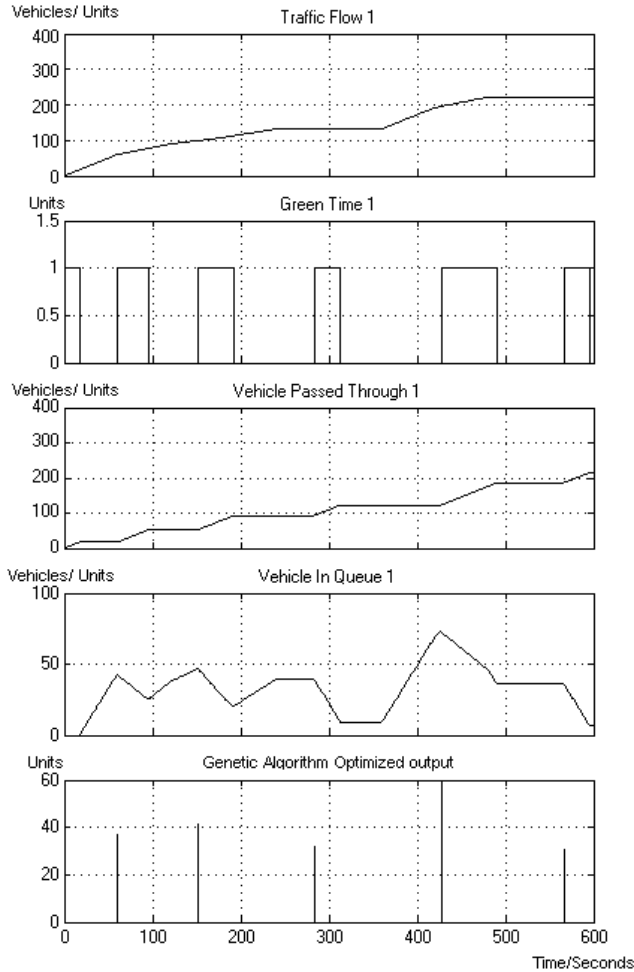


Figure 2. Output scope of the GA model

Another aspect of success can be seen from the output scope is the number of the cycle times in 600 seconds of simulations. The genetic algorithm traffic flow control simulation generated 6 cycle times for the traffic lights system from the second graph. The large number of cycles will results more amber time and lost time which reducing the efficiency of the traffic light system. As for the genetic algorithm output at the last graph in Fig. 2, it shows that the genetic algorithm successfully optimizing the traffic signal according to the queue length.

E. Effects From Incoming Traffic Flows

The incoming traffic flows is the main concern that will cause disturbance upon the traffic flow control. Incoming traffic flow is continuous and uncontrollable by the system. It will still bring disturbance even the incoming traffic flow is small. The impact caused by the continuous incoming traffic flow is significant during the red signals or stoppage time, when no vehicles are allowed to pass through the traffic intersection and therefore caused the queue length to be increased even more.

Thus, the effect of the incoming traffic flow needed to reduce to a minimum point to ensure the smoothness of the traffic flow within the intersection. It is not enough to take the queue length or number of vehicles waiting at the traffic lights from all the phases within the intersection at that particular moment and feed into the genetic algorithm for the processing, because there are still nonstop of incoming traffic flow into the intersection. The problem can be clearly seen in a situation when phase 1 allows vehicle to pass through the intersection, and phase 2 and 3 still accumulating vehicles from the incoming traffic flow. If only the queue length at that particular moment is taken into consideration, then the effect of the incoming traffic flow will cause more queue length to be happened at the next cycle of traffic light system.

In order to minimize the effect of the incoming traffic flow, the traffic flow control needs to have the ability to predict the incoming traffic flow within that cycle. That will ensure the traffic flow control to make a better optimization decisions for that cycle of traffic signals.

Genetic algorithm traffic flow control takes the queue length from all phase at the very beginning of a new cycle, that make the first phase's queue length to have the minimum impact from the incoming traffic flow. Let time to be zero at the beginning of a new cycle, then the queue length of first phase is not increased due to the incoming traffic flow does not arrive at the intersection at the initial time. In the second phase and the third phase, the situations are totally different, as second phase need to wait for its permission signal to pass through after the first phase of the cycle and third phase is the last phase in the cycle which causes it to have the longest waiting time compare to second phase. As the incoming traffic flow is continuously flow into the intersection, second phase and third phase suffer from the accumulating vehicle that is increasing during the waiting time for their turn.

The prediction of the lengthened queue length at second phase and third phase due to the incoming traffic flow can be done by the following algorithm. Since first phase does not suffer from the impact of incoming traffic flow, its green time (chromosome) is still estimated by the genetic algorithm in the same way. As for the second phase, the genetic algorithm will take in the waiting time of the second phase as parameter for the estimation of the new queue length. In this case, the waiting time appear to be the green time for the first phase. Then, the third phase will take the total green time of first and second phase as its waiting time for the estimation of its new queue length.

Genetic algorithm traffic flow control will then taking consideration of the waiting time of second and third phase along with their incoming traffic flow rate, to generate the green time (chromosome) for them.

$$Q_k + Tf_k(Gt_1 + \dots + Gt_{k-1}), k = 1, 2, 3 \dots \quad (2)$$

Equation (2) shows the relationship of the queue length in each phase. The variable, k represents the number of phase, while variable P is the new queue length or the total

of vehicles estimated. Variable T_f is the incoming traffic flow rate in second which can be multiplied with the variable G_t , green time of each phase to get the number of vehicle accumulated during the waiting time. Then, variable Q is the current queue length of that phase.

IV. RESULTS AND DISCUSSIONS

The genetic algorithm traffic flow control is simulated with the same condition as previous. The simulation is run for 600 seconds and the only difference is the incoming traffic flow is involved in the optimization algorithm with the genetic algorithm in this simulation. The results are as shown as in Fig. 3.

Fig. 3 shows the results of the simulation in the traffic phase 1. The dotted line represents the genetic algorithm without involving incoming traffic flow and the solid line is the graph of the genetic algorithm with incoming traffic flow. As can be seen from the graph, the green time is the period when the number of vehicles decreases periodically.

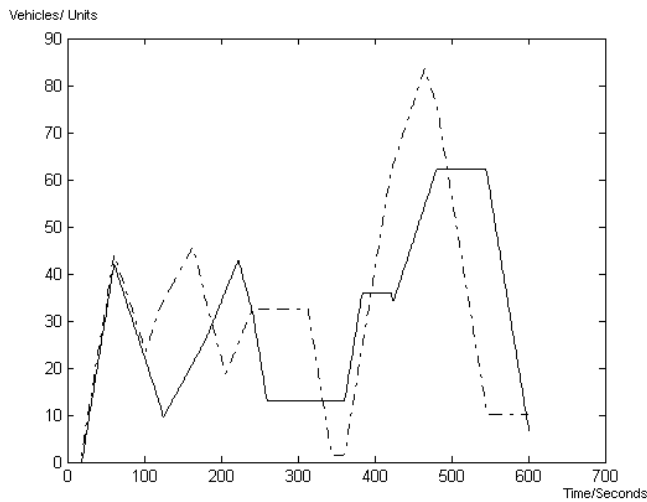
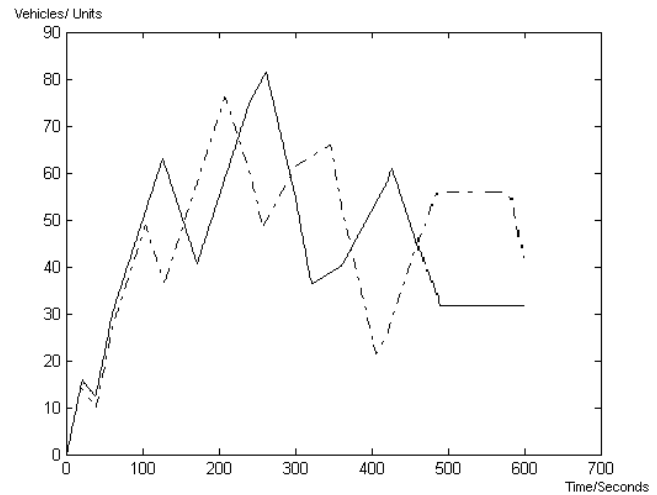


Figure 3. Phase 1 simulation results

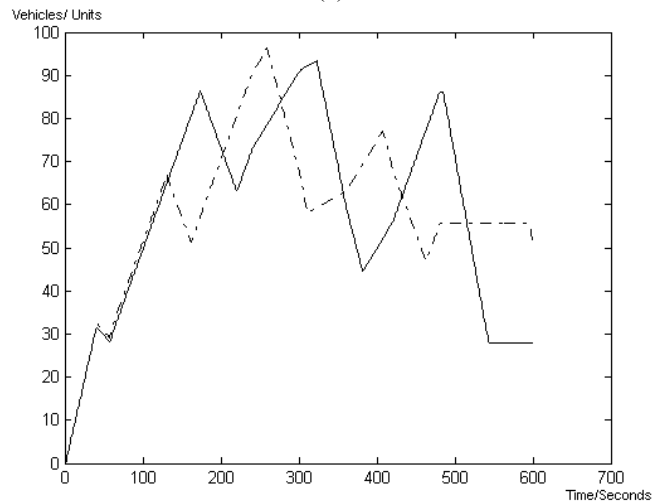
From the graph, the solid line did not fluctuate too much compare to the dotted line. The dotted line shows extreme low and extreme high value which means that it fails to do the optimization as it has the moment of taking too long of green time from the cycle time, and also the moment of accumulated too many vehicles at the intersection. If one phase is having a too long green time, it cannot reach a mutual benefit between all the phases, because other phases need to sacrifice their green time to that particular phase. That will cause the other phases to suffer from over accumulated number of vehicles. The extreme high value from the graph also shows that it fails to distribute the green time fairly between all the phases, resulting some of the phases having longer green time while other suffer from more accumulated number of vehicles. Different from the dotted line, the results of the solid line can be seen as stable, adaptable and able to pass through more vehicles than the dotted line graph. This shows that by considering the incoming traffic flow into the genetic algorithm traffic flow

control, the results of the simulation are improved. The genetic algorithm with the incoming traffic flow is able to pass more vehicles through the intersection within the same simulation time and it able to distribute the green time more fairly.

As for phase 2, the simulation results are shown in Fig. 4(a), where the dotted line again represents the genetic algorithm without involving the incoming traffic flow and the solid line is the graph of the genetic algorithm traffic flow control after considering the incoming traffic flow. The performance of the genetic algorithm traffic flow control after considering the incoming traffic flow is better than the previous genetic algorithm from the graph. It was able to pass through more vehicles than the previous genetic algorithm at the end of the simulation. Even though, the solid line shows the highest peak throughout the simulation, but it manage to generate more green time to release more vehicles rapidly.



(a)



(b)

Figure 4. Phase 2 and 3 simulation results

As for phase 2, the simulation results are shown in Fig. 4(a), where the dotted line again represents the genetic algorithm without involving the incoming traffic flow and the solid line is the graph of the genetic algorithm traffic flow control after considering the incoming traffic flow.

The performance of the genetic algorithm traffic flow control after considering the incoming traffic flow is better than the previous genetic algorithm from the graph. It was able to pass through more vehicles than the previous genetic algorithm at the end of the simulation. Even though, the solid line shows the highest peak throughout the simulation, but it manage to generate more green time to release more vehicles rapidly.

In Fig. 4(b), the dotted line and the solid line represent the previous genetic algorithm and the genetic algorithm after considering the incoming traffic flow for the phase 3. The results are more or less the same compare to the other 2 phase simulation. The solid line has better performance over the dotted line throughout the simulation, where the number of vehicles yield at the end of the simulation is less for the solid line.

V. CONCLUSION

In this paper, the studies on traffic characteristic have been done. The traffic flow control is also being built up with genetic algorithm with the ability of self tuning to find out the most optimum chromosomes or solutions.

The effects of various traffic characteristics are also being studied in this paper. As for queue length, which is also the total number of vehicles waiting at the intersection to be given the permission to be passed through, it is known as the performance indicator. Besides that, queue length also may bring some effects toward the traffic flow control, as the queue length may be too long and was unable to be released by the traffic flow control fast enough to ensure the smoothness of the traffic flow within the intersection.

Cycle time and the number of traffic signal cycle also have a big influence toward the traffic flow control. This is because cycle time is the duration of time that determine how long the queue length need to wait until they are released by the intersection after their permission is retrieved by the traffic flow control. The number of the traffic signal cycle

will affect the sizes impact of the lost time can deal upon the traffic flow control. Lost time is the time lost during the traffic flow control due the amber time and the drivers' behavior.

Genetic algorithms' characteristic to evolve through generations of chromosomes and solution to choose the fittest optimum chromosomes that let it has the ability to self-optimizing from generation to generations. In this paper, the genetic algorithm is used in the traffic flow control to optimize the traffic flow within the intersection. The genetic algorithm is shown to be effective and capable to do the optimization of the traffic flow.

The increasing of queue length during the waiting time is later reduced by introducing the incoming traffic flow into the genetic algorithm. A new queue length is estimated from the incoming traffic flow rate and then the green time is then generated by the genetic algorithm for the optimization of the traffic flow control within the intersection.

The simulations' results showed that the genetic algorithm is a successful method to be used in the traffic flow control, as the genetic algorithm able to give a fast respond to the changes of the queue length at the intersection.

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