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PROPOSED TRAFFIC LIGHT VARIABLE TIME SCHEDULING ALGORITHM DEPENDENT ON VEHICLE VOLUME

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A B S T R A C T

This paper studies the flow of vehicular traffic in an intersection and proposes an algorithm to improve the volume of vehicle crossing it. Fixed-time schedule is a standard setup for regular traffic light systems that becomes inefficient when the green light time allotted is much greater than the time it takes for the actual number of vehicles to cross the intersection. This work considers the traffic flow in a six-lane four-way intersection and proposes a variable timing algorithm to improve the efficiency of vehicles crossing compared to a fixed-time schedule. The proposed adaptive algorithm takes into account the number of vehicles in queue to derive the green time to be set for each of the lane. Simulation results under various conditions (varying vehicle volume vehicles per lane as well as varying the traffic flow scheme) showed that the proposed variable-timing has significant improvement over fixed-timing schedule in terms of the total time it took to let all the vehicles in queue cross the intersection

1. INTRODUCTION

Traffic congestion (Salman & Alaswad, 2020) became an issue by the second half of the 20th century even if transportation itself has always been of integral value to the society. It was because of the dramatic growth in the number of vehicles on the road as well as the demand for various modes of transportation. A large number of vehicles utilizing a common infrastructure with limited capacity leads to traffic bottleneck. The traffic infrastructure is fully utilized in an ideal scenario but this traffic bottleneck causes long queues leading to delays (Bull & CEPAL, 2003).

Competing traffic flows are timed and controlled through traffic lights. Traffic light systems using cyclic light schedules have been utilized since 1968 when traffic light signals were utilized at Westminster crossing in London to manage the flow of traffic at road intersections. In the 1960's, countries all over the world started research works on linking coordinated signals and proposed mathematical models of several traffic flow situations at intersections in order to derive the optimal signal timing.

But traffic flow efficiency is affected due to the delay caused by queueing of the vehicles at road intersections. Several research works have been done with the objective of increasing traffic efficiency through

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algorithms that decide the timing of the traffic lights. This led to vehicle delays at signalized road intersections being minimized through scheduling of traffic lights (Wen et al., 2019).

Total volume of vehicle crossing must complete a cycle, usually defined in seconds, for the display system of the traffic signal to work well. It refers to the overall number of vehicles passing through the intersection, the entry way and stop line for a certain period of time. The capacity of a road intersection is closely linked to both road and traffic conditions as well as factors of the chosen control strategy (traffic flow rate, types of vehicle, speed, non-motorized vehicles, effect of pedestrians, lane/road functions, etc.). The saturation of the road intersection can be checked with respect to its traffic capacity (Rodegerdts et al., 2004).

The isolated traffic light intersection wherein the traffic signal are set dependent on the real-time traffic has received a lot of attention from researchers (Alwan & Salman, 2022, 2023; Ye et al., 2022; Bani Younes & A. Boukerche, 2016). The vehicular volume, traffic speed, and number of vehicles are some of the factors taken into consideration when deciding the sequence phase cycles for the intersection.

A very critical aspect of the study of transportation is traffic signal control. The development of several applications and improved traffic control systems are some of the fascinating and cutting-edge research works in traffic signal. Traffic control is an essential component of a traffic system which is why several studies have looked for ways to improve traffic management. A good traffic signal control can shorten the waiting time for vehicles to move through the intersection eventually leading to reduced traffic congestion (Afrin & Yodo, 2020). This means that an effective scheduling technique reduces the average delay and increases the throughput of the intersection (Younes & Boukerche, 2013).

Providing the right of way to drivers helps improve road safety. Safety concerns are the main force behind traffic management which is the prevention of two vehicles being in the same location at the same time (Armah et al., 2010). In addition to safety, there is also the reduction in the number of halts made by the individual vehicles (Bellemans et al., 2006). Ensuring that road traffic is moving smoothly by lowering the time spent on the road as well as to how many times they must stop has a positive impact on the comfort and safety in road traffic, among other things, through reduced air pollution and number of vehicle-related accidents. An effective traffic control system utilizes an algorithm that adjusts to the number of vehicles arriving at the intersection.

The headway among the number of vehicles per second is essential. The queue post indicating the start of the saturation period is determined by continuously comparing the mean headways of queue locations. The queue length or if the headway exceeds, determine the termination of saturation period per signal (Kerner, 2014). It is imperative that the saturation period of the traffic flow through the intersection is accurately determined so as to derive the volume of vehicles per second. The length of time from the beginning of the queue determines the start of the saturation period.

Several studies have proposed adaptive type systems that primarily utilized sensors or array of sensors. Shinde exploited Adaptive Traffic Light Control System (ATLCS) that utilized a network array of sensors for sensing traffic (Shinde, 2017). The waiting time are kept at a minimum through the variable and intelligent timing intervals of the green and red lights at each intersection. The optimization of traffic light switching increased road capacity, reduced travelling time and prevented traffic congestion.

Chavan made use of "intelligent traffic light controller" for a more efficient traffic light control (Chavan et al., 2009). The timing of green and red light at each road intersection is intelligently decided based on the overall traffic in all the adjacent roads. Their optimized traffic light switching increased traffic flow and road capacity as well as avoid traffic bottleneck. A distinctive feature is the GSM cell phone interface for the drivers who wants to obtain latest traffic status on congested roads.

Li proposed a real-time control scheme for traffic lights based on the on-board Electronic Toll Collection in order to reduce the carbon dioxide emission of vehicles (Li & Shimamoto, 2011). The optimal average waiting time is calculated as well as the carbon dioxide reductions. Road conditions are acquired through wireless communications from the traffic light systems and the other vehicles based on Dedicated Short-Range Communication protocol.

Some studies have employed embedded systems (Chavan et al., 2009), image processing (Al Okaishi et al., 2019), deep learning (Liang et al., 2019), control (Sakthimohan et al., 2023), and fuzzy (Kumar et al., 2021). Chavan's work which utilized a sensor network with an embedded system is user-friendly, with quick response time, has a simple architecture, and is expandable.

A real-time image processing based system for estimating traffic density as the input in adjusting the timing of the traffic light was proposed by Al Okaishi (Al Okaishi et al., 2019). It was for an effective traffic control system that will minimize shutdowns and delays at intersections with traffic lights that could lead to lower fuel consumption, decrease travel time and reduce greenhouse emissions.

A deep reinforcement learning model for controlling traffic light cycle was presented by Liang for deciding what will be the duration of traffic signal based on the data collected from several sensors (Liang et al., 2019). It demonstrated that efficiency can be improved by dynamically updating the traffic light duration depending on the real-time traffic information.

The Finite State Machine (FSM)-based controller proposed by Sakthimohan utilized a modular and deterministic method to traffic signal control (Sakthimohan. et al., 2023). The FSM model is set to accommodate varied traffic patterns while prioritizing vehicle and pedestrian movement. The controller is designed to maximize throughput, minimize delays and improve the intersection efficiently by coordinating the traffic movements.

The Dynamic and Intelligent Traffic Light Control System presented by Kumar (Kumar et al., 2021) receives the real time traffic data in order to dynamically adjust the duration of traffic light. The system was designed to tackle several issues such as long waiting time, fuel wastage and increased carbon emission aside from the main objective of increasing the efficiency of a traffic light control system.

The common and important aspect among all these is the switching from conventional fixed-time traffic light signal system to a more efficient traffic light signal system. Fixed-time scheduling is a standard setup for regular traffic light systems that becomes inefficient when the green light time allotted is much greater than the time it takes for the actual number of vehicles in queue to cross the intersection.

In this work, a variable time scheduling algorithm for a traffic light signal system is proposed wherein the number of vehicles on queue is taken into consideration. The proposed algorithm is then demonstrated by being utilized as the traffic signal control system for a simulation of a six-lane four-way road intersection. Its performance is then evaluated under various situations with random number of vehicles per lane per way for two traffic flow schemes. Simulation results showed that the proposed variable-time traffic signal system is more efficient compared to a fixed-time traffic signaling system.

2. METHODOLOGY

A. Isolated Traffic Light Intersection Environment

The isolated traffic light independently regulates traffic flow at a road intersection regardless of signalized intersections in the vicinity. The timing variables for the traffic light intersection are set by taking into consideration the real-time traffic situation wherein the traffic light signaling system at such an intersection manage and schedule the arrangement of the traffic flow. Purposive sampling was utilized to meet the conceptual and substantial need of the research, with the following inclusion and exclusion criteria:

B. Traffic Flow Schemes Simulated

B.1 Per WAY: ALL GO the same time

A typical six-lane, four-way road intersection is shown in Fig. 1 to include 3 directions per way (turn left, go forward and turn right). For the first traffic flow scheme, all the vehicles in the three-lanes of the current WAY proceed to their desired direction at the same time. The procedure is described as:

(1) Vehicles in WAY 01 advancing first (Fig. 2.a) within GREEN time;
(2) Followed by all the vehicles in WAY 03 (Fig. 2.b) within their GREEN time;
(3) Then all the vehicles that can pass from WAY 02 (Fig. 2.c) within their GREEN time:
(4) Finally, all the vehicles in WAY 04 (Fig. 2.d) that can cross within their GREEN time;
(5) Then back to letting the vehicles in WAY01 pass through (1).

This scheme is further split into Operation 1 and Operation 2. The fundamental difference between Operation 1 and Operation 2 is that **Operation 1 does not** consider the number of vehicles queuing in the current WAY, therefore the default time is used as the ***max_time***. On the other hand, the number of vehicles queuing in the current WAY **is taken into consideration in Operation 2** by utilizing the proposed algorithm to set the value for ***max_time***.

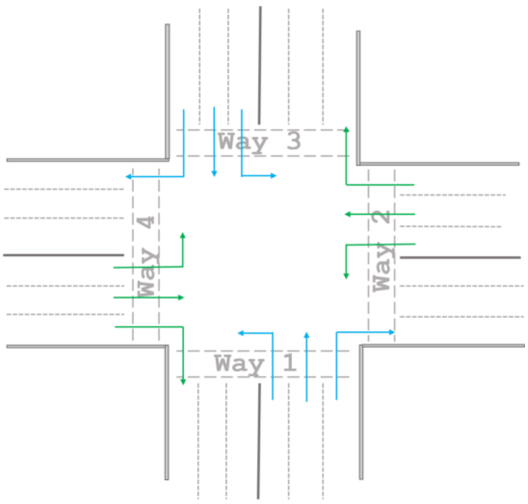

Figure 1. Typical six-lane, four-way road

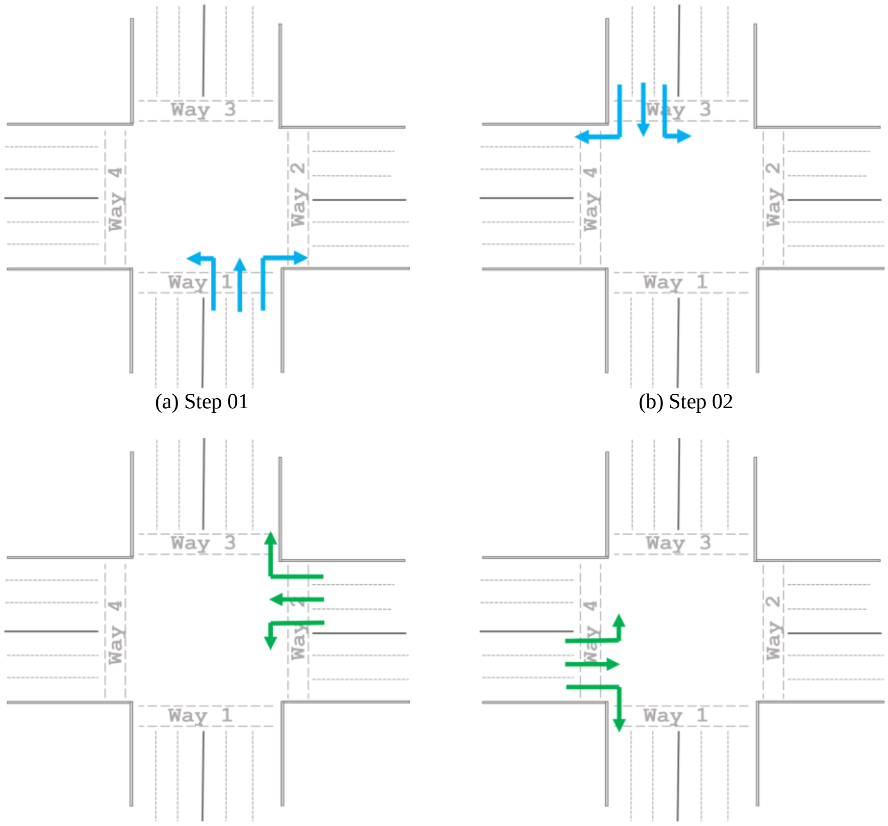

Figure 2. Operations 1 and 2 traffic flow

B.2 Opposing WAYS: LEFT GO First then FORWARD & RIGHT GO same time

For the second traffic flow scheme, it involves two opposite WAYS (WAY01 & WAY03, WAY02 & WAY04) operating at the same time. The vehicles turning left in opposite ways move at the same time then the remaining vehicles (going forward and turning right) in the same opposite ways move to their desired direction also at the same time.

(1) The vehicles in the opposing ways (WAY01 & WAY03) turning left move at the same time within GREEN time (Fig. 3.a);
(2) Then the vehicles (going forward and turning right) in the current opposing ways (WAY01 & WAY03) move to their desired direction also at the same time within their GREEN time (Fig. 3.b);
(3) The vehicles in the next set of opposing ways (WAY02 & WAY04) that wants to turn left move at the same time within their GREEN time (Fig. 3.c);
(4) Followed by the vehicles (going forward and turning right) in the next opposing ways (WAY02 & WAY04) moving towards their desired direction also at the same time within their own GREEN time (Fig. 3.d);
(5) Back to Step (1).

Similar to the first traffic flow scheme, this second scheme is further split into Operation 3 and Operation 4. The same fundamental difference between Operations 3 and 4 is applied in which Operation 3 does not consider the number of vehicles in queue in both opposing WAYS hence the default time is used as the max_time. On the other hand, the number of vehicles in queue in both the opposing WAYS are taken into consideration in Operation 4 by utilizing the proposed algorithm to set the value for max_time.

C. Proposed Variable Time Scheduling Algorithm

This work presents a proposed time variable scheduling algorithm for traffic control that takes into consideration the volume of vehicles in a road intersection. It examines a typical six-lane four-way road intersection, wherein the proposed algorithm was simulated for traffic signal control at a traffic intersection for two different traffic flow schemes. Vehicles arrive at the road intersection at various estimated times; hence the total number of vehicles in queue varies. During each process, one or more vehicles pass through the intersection while the traffic light is green. The number of vehicles queueing in the ready area (Fig. 4) determine the duration of each process.

C.1 Flowchart

The flowchart of the implemented traffic flow schemes controlled using the proposed algorithm is given in Fig. 5. It starts by initializing the given parameters for each way as follows:

- volume of vehicles turning left, going forward and turning right
- default time set for turning left, going forward and turning right
- initial calculated time for turning left, going forward and turning right

The simulation algorithm checks whether the scheme to be implemented is the first one (*Per WAY: ALL GO the same time*) or the second (*Opposing WAYS: LEFT GO First then FORWARD & RIGHT GO same time*). It then also checks whether the timing to be used is the set default time or the carriable calculated time. Deciding the optimal time for the operation begins with calculating the time to finish for each direction of each way that by using equation (1):

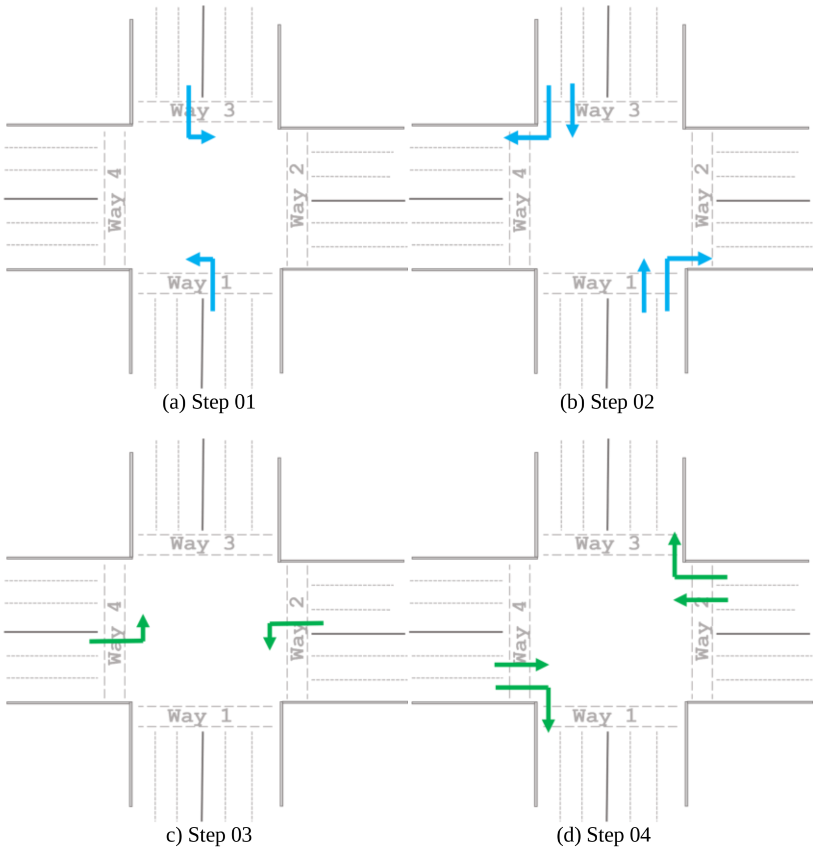

Figure 3. Operations 3 and 4 traffic flow

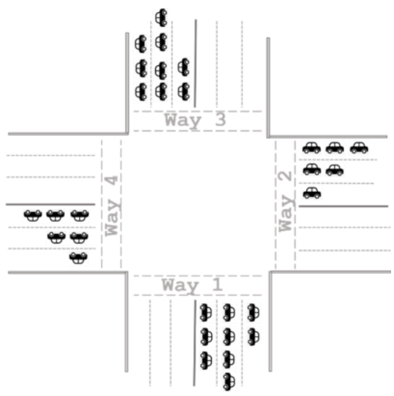

Figure 4. Ready area for the six-lane four-way road intersection

$$calculated\_time = (time\_to\_exit\_box) + \begin{pmatrix} (total\_vehicles\_in\_queue - 1) \\ *(time\_to\_move\_one\_slot\_fwd) \end{pmatrix} \quad (1)$$

The largest default set time per way (turning left, going forward & turning right) is selected. Then we take the value for calculated time per way ((turning left, going forward & turning right). If the largest default set time is greater than the largest calculated time then "**maximum time = *largest default set time***" else "**maximum time = *largest calculated time***". The system then proceeds to execute the specified traffic flow scheme with the corresponding operation using the maximum time set.

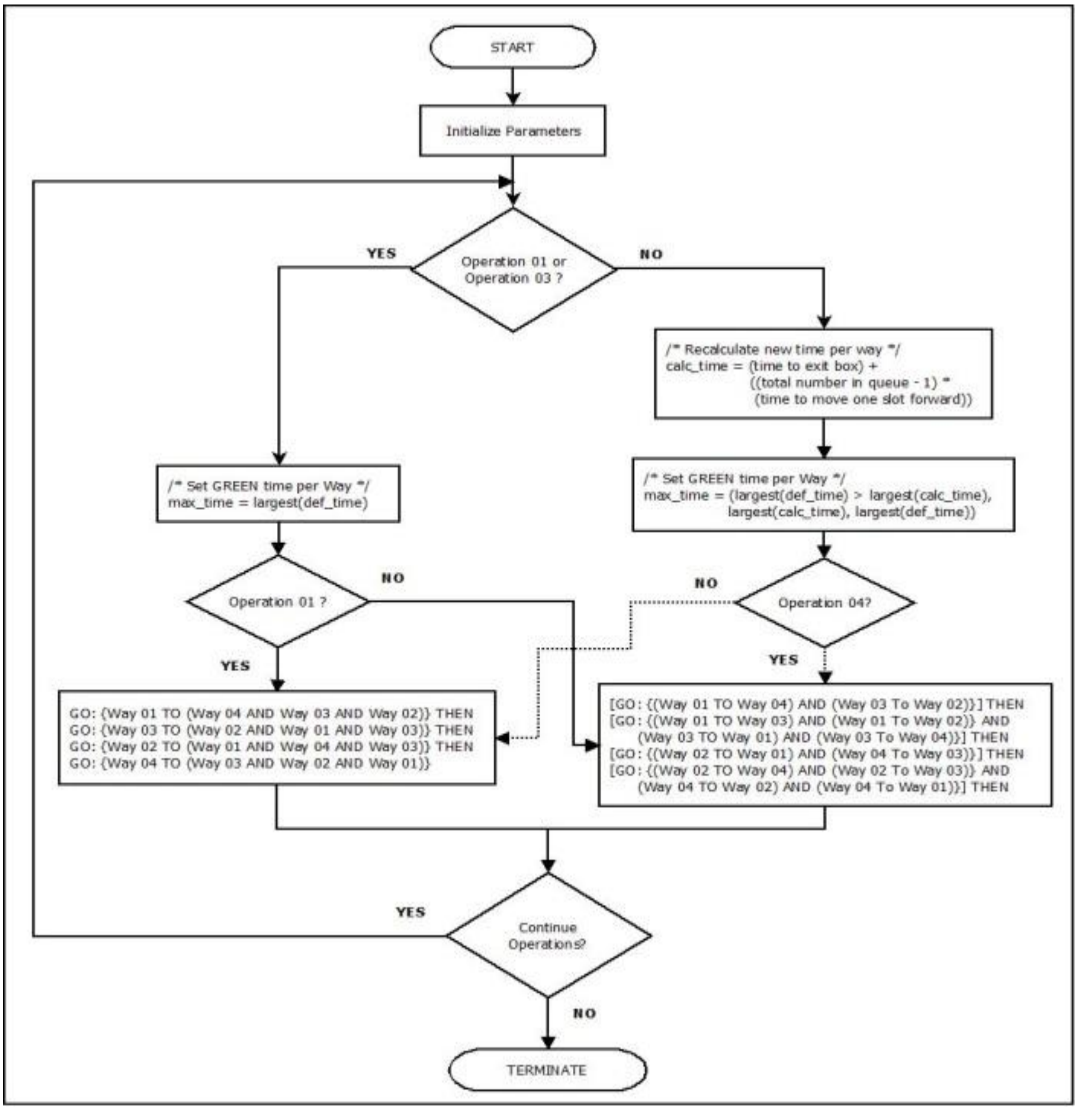

Figure 5. Flowchart of operation with proposed algorithm

C.2 Pseudocode of proposed traffic light system

1. INITIALIZE PARAMETERS

➢ Parameters for each way (road)
- ***vol_left, vol_fwd, vol_right***
- ***time_left, time_fwd, time_right***
- ***time_def_left, time_def_fwd, time_def_right***

➢ Standard time for vehicle to enter, exit intersection box as well as move one slot forward
- ***go_left, go_fwd, go_right, move_one_slot_up***

2. SELECT WHICH OPERATION

➢ **OPERATION 1**

(volume of vehicles **NOT** considered)
(vehicles going in **ALL** directions per way move at the same time)

- Select which defined time is largest
  ***largest_def* = largest(*def_left, def_fwd, def_right*)**
- Set ***largest_def*** as ***max_time***
  {**GO**: **WAY 1** to **(Left** & **Forward** & **Right)**} →
  {**GO**: **WAY 3** to **(Left** & **Forward** & **Right)**} →
  {**GO**: **WAY 2** to **(Left** & **Forward** & **Right)**} →
  {**GO**: **WAY 4** to **(Left & Forward** & **Right)**}

➢ **OPERATION 2**

(volume of vehicles **IS** considered)
(vehicles going in **ALL** directions per way move at the same time)

- Calculate revised time per direction depending on vehicle volume, using eq (1)
- Select which defined time is largest
  largest_def **= largest(*def_left, def_fwd, def_right)***
- Select which defined time is largest
  largest_calc **= largest(*calc_left, calc_fwd, calc_right)***
- Set ***max_time***
  if ***largest_def*** > ***largest_calc*** then
  max_time = ***largest_calc***
  else ***max_time*** = ***largest_def***

{**GO**: **WAY 1** to **(Left** & **Forward** & **Right)**} →
{**GO**: **WAY 3** to **(Left** & **Forward** & **Right)**} →
{**GO**: **WAY 2** to **(Left** & **Forward** & **Right)**} →
{**GO**: **WAY 4** to **(Left & Forward** & **Right)**}

➢ **OPERATION 3**
(volume of vehicles **NOT** considered)
(vehicles going **LEFT** move first, then those going **FORWARD** & **RIGHT**)

- Select which defined time is largest
  largest_def **= largest(*def_left, def_fwd, def_right)***
- Set ***largest_def*** as ***max_time***

{**GO**: (**WAY 1** to **Left)** & (**WAY 3** to **Left)**} →
{**GO**: (**WAY 1** to **Forward & Right)** & (**WAY 3** to **Forward & Right)**} →
{**GO**: (**WAY 2** to **Left)** & (**WAY 4** to **Left)**} →
{**GO**: (**WAY 2** to **Forward & Right)** & (**WAY 4** to **Forward & Right)**} →

➢ **OPERATION 4**
(volume of vehicles **IS** considered)
(vehicles going **LEFT** move first, then those going **FORWARD** & **RIGHT**)

- Calculate revised time per direction depending on vehicle volume, using eq (1)
- Select which defined time is largest
  largest_def **= largest(*def_left, def_fwd, def_right)***
- Select which defined time is largest
  largest_calc **= largest(*calc_left, calc_fwd, calc_right)***
- Set ***max_time***
  if ***largest_def*** > ***largest_calc*** then
  max_time = ***largest_calc***
  else ***max_time*** = ***largest_def***

{**GO**: (**WAY 1** to **Left)** & (**WAY 3** to **Left)**} →
{**GO**: (**WAY 1** to **Forward & Right)** & (**WAY 3** to **Forward & Right)**} →
{**GO**: (**WAY 2** to **Left)** & (**WAY 4** to **Left)**} →
{**GO**: (**WAY 2** to **Forward & Right)** & (**WAY 4** to **Forward & Right)**} →

3. BACK TO 2

3. RESULTS AND DISCUSSION

A. Comparative Result

Fixed-time and variable-time scheduling algorithms were simulated under nine conditions with varying parameters. The fixed-time scheduling algorithm had its default set time values for all the lanes of Way 01, Way 02, Way 03 and Way 04 set as shown in Table 1 (see Appendix). On the other hand, the time values for variable-time algorithm is calculated as described in Section II.C (Proposed Variable-Time Scheduling Algorithm).

The number of vehicles queueing per lane per way utilized for both fixed-time and variable-time scheduling is listed in Table 2 (see Appendix). The total time it took to process all the vehicles in queue per condition is given in Table 3 (see Appendix). They are listed per traffic scheme per operation type as described in Section II.B (Traffic Schemes Simulated).

Table 4 (see Appendix) show the comparative results as a percentage of improvement of variable-time over the fixed-time scheduling algorithm. It can be seen that for the first traffic flow scheme one (Section II B.1: Per WAY: ALL GO the same time), the variable-time scheduling showed an improvement over fixed-time in the range of 0.08% to 30.02% except for Condition VI where there was a degradation of 0.07%. On the other hand, for the second traffic flow scheme (Section B.2: Opposing WAYS: LEFT GO First then FORWARD & RIGHT GO same time), the variable-time scheduling showed an improvement over the fixed-time in the range of 7.50% to 47.50%.

Overall, the proposed variable-time scheduling showed better performance over the fixed-time in terms of total processing time to let all the vehicles in queue pass through the intersection.

4. CONCLUSION

This work presents a variable time scheduling algorithm for traffic flow control taking into consideration the traffic characteristics of the traffic flow in terms of the volume of vehicles in queue. The objective was to increase traffic flow and the number of vehicles crossing the intersection by reducing waiting time and minimizing queue delays. The study aimed to design and assess the effectivity of traffic light signaling by focusing on the number of vehicles that can pass through. It determined if variable-time algorithm is better than fixed-time algorithm for traffic control scheduling.

The isolated traffic light regulates traffic at each intersection independently, regardless of any neighboring signalized intersections. The intersection has twelve traffic direction, with two concurrent traffic flows. The timing variables, which can include cycle length, phases, interval splits, and offset parameters, are set based on traffic volume. The proposed time variable scheduling algorithm considers the volume of vehicles at the intersection. The duration of each process depends on the number of vehicles and ready area during data collection.

The fixed-time and variable-time scheduling algorithms were simulated for the given traffic schemes under nine conditions with varying parameters. The default processing time used in fixed-time scheduling was manually set while the processing time for variable-time scheduling was calculated with the proposed method using the actual number of vehicles in queue. The number of vehicles in queue for each condition was set up in order to test the performance of the proposed methodology.

The overall comparative result as a percentage of improvement of variable-time (calculated) over the fixed-time (default) scheduling algorithm showed improvements in Scheme 1 (Section II B.1: Per WAY: ALL GO the same time) for all conditions (in the range of 0.08% to 30.02%) except for Condition VI (a degradation of 0.07%) while Scheme 2 (Section B.2: Opposing WAYS: LEFT GO First then FORWARD & RIGHT GO same time) showed improvement over all conditions (in the range of 7.50% to 47.50%). The results suggest that the proposed algorithm is effective in reducing traffic congestion and improving overall traffic flow.

Based on the results of the simulation, we have seen that it takes shorter time for variable-time algorithm to let all vehicles pass through the intersection compared to fixed-time algorithm. We can infer from it that more vehicles can pass through the intersection for a given time frame when using variable-time algorithm. Hence, we can conclude that the using the proposed variable-time algorithm as the traffic control strategy is better than the fixed-time algorithm. Further studies can be done by testing and implementing the proposed traffic system with sensors for accurately detecting the number of vehicles in the ready area.

To finalize, important features in the design of an enhanced traffic control system should include the linking of traffic signals, traffic control centers and GIS-enabled road maps through the smart computational power of data analytics as an integral aspect (Singh et al., 2016). The underlying challenge is in the utilization of real time analytics on traffic information and properly applying it to some traffic flow (Yuan et al., 2015; Lv et al., 2016). A traffic management system (Singh et al., 2016) supplies the data to data analytics tools (Puiu et al., 2016; Fotopoulou et al., 2016) which in tandem with real-time GIS mapping provides valuable information to vehicle drivers as well as lessen traffic congestion.

Basic information for tourist such as places to visit, parking areas and distance to drive are shown in big digital screens in real-time around city center entrances (N. Kumar et al., 2017) as a guide to the drivers. This is to help save on time and fuel that would have been otherwise spent when searching for various places to visit (Ianuale et al., 2016). It also fulfills smart living in metro areas (Kumar et al., 2017) since the environment becomes more hygienic and pollution free (Alshawish et al., 2016).

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APPENDIX

Table 1. Parameters for fixed-time scheduling (default time per direction per way)

Default time set for Fixed Time operation (in seconds)									
Default Time set for all (Way01, Way02, Way03, Way04)	**Condition**								
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Default time set turn Left	20	20	20	30	30	25	20	15	10
Default time set go Fwd	15	15	15	25	30	25	20	15	10
Default time set turn Right	15	15	15	20	30	25	20	15	10

Table 2. Parameters for both fixed- & variable-time (number of vehicles in queue)

Vehicles in queue (in number of vehicles per queue per way)									
Way & Direction	**Condition**								
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Way 01									
Turn Left	20	10	10	20	10	10	10	10	10
Go Fwd	20	20	20	10	20	20	20	20	20
Turn Right	8	8	8	12	8	8	8	8	8
Way 02									
Turn Left	8	10	10	20	10	10	10	10	10
Go Fwd	16	20	20	10	20	20	20	20	20
Turn Right	2	8	8	12	8	8	8	8	8
Way 03									
Turn Left	9	9	10	20	10	10	10	10	10
Go Fwd	10	10	20	10	20	20	20	20	20
Turn Right	8	8	8	12	8	8	8	8	8
Way 04									
Turn Left	12	9	10	20	10	10	10	10	10
Go Fwd	16	10	20	10	20	20	20	20	20
Turn Right	5	8	8	12	8	8	8	8	8

Table 3. Total processing time for both fixed- & variable-time under conditions I – IX

Processing time (time in seconds)										
Traffic Scheme	**Type of Operation**	**Condition**								
		I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Per WAY: ALL GO the same time	*Operation 01 (fixed time)*	87.85472	87.85907	87.88726	130.05561	131.8633	109.93052	87.86285	65.94747	43.98926
	Operation 02 (variable time)	70.35067	68.12664	87.92278	91.05721	92.28393	92.30583	87.92338	65.89768	43.94925
Two ways Left then Fwd & Right together	*Operation 03 (fixed time)*	87.91466	87.87708	87.88707	130.13571	131.87998	110.04712	88.08017	65.94466	43.96099
	Operation 04 (variable time)	81.3185	65.94016	65.95084	68.51215	69.23614	69.38077	65.89335	49.45931	32.96388

TABLE 4. Percent improvement of variable-time over fixed-time scheduling

Improvement (variable time compared to fixed time)										
Traffic Scheme	**Type of Operation**	**Condition**								
		I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Per WAY: ALL GO the same time	*Operation 01 (fixed time)* / *Operation 02 (variable time)*	19.92%	22.46%	-0.04%	29.99%	**30.02%**	16.03%	**-0.07%**	0.08%	0.09%
Opposing WAYS: LEFT GO First then FORWARD & RIGHT GO together	*Operation 03 (fixed time)* / *Operation 04 (variable time)*	**7.50%**	24.96%	24.96%	47.35%	**47.50%**	36.95%	25.19%	25.00%	25.02%