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Simulation of Green-Wave Traffic Control System in Road-Networks

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ABSTRACT: *Trafficcongestions at intersections cause delay, which leads to economic losses in travel time, vehicle operating costs and environmental pollution from vehicular emissions. Vehicles moving through several traffic signal-controlled intersections mostly experience very high travel-times as they have to stop at almost every intersection on the path to destinations. This inefficient traffic flow is mainly caused by lack of coordination between adjacent traffic signal controls. The simulation and execution of four traffic signal-controlled intersections network with a coordinated traffic flow called green wave, and without green wave were compared using the R-package software. With varying traffic specifications of distances covered, vehicle velocities and traffic volumes, the green wave traffic signal control system in the road-network significantly minimizes the travel times of vehicles when compared with the same traffic conditions but without green wave. The result also shows that the application of green wave technology is feasible and efficient on any traffic signal-controlled road network.*

KEYWORDS *-Green wave; Offset; Dilemma zone; Cycle length; Perception/Reaction time; Progression speed*

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I. INTRODUCTION

1.1 Background of the Study

Traffic is the movement of vehicles and people in a particular place or for a particular purpose. The true origin of traffic control is unknown but historical evidence has shown that traffic problems emanated when main roads came into existence. Man has always had problems with roads filled with travelers[1]. The Federal Highway Administration (FHWA) stated that traffic congestion is one of the main problems in every developing country [2]. This congestion causes delay at intersections and leads to economic losses. These losses can be in the form of inefficient time management since the vehicles must wait for the lights to change; waste of consumables like fuel, and the emission of carbon monoxide from the vehicles are health hazards to the environment and on the quality of life of the people.

One common approach to handle traffic congestion is to build infrastructures such as roads, bridges, by-pass lanes, flyovers and a host of others. It is becoming increasingly more difficult to build more infrastructures to at least diminish traffic jams. Not only the high cost, but also the lack of space and the environmental damage of building new road have to be considered [3].A study in *The American Economic Review* (2011)indicates that there may be a "fundamental law of road congestion." According to National Electrical Manufacturers Association (NEMA), it is determined that the number of Vehicle-Kilometers Traveled increases in direct proportion to the available lane-kilometers of roadways [4]. The implication is that building new roads and widening existing ones only results in additional traffic that continues to rise until peak congestion returns to the previous level.

Another approach in reducing traffic congestion is the introduction of Traffic Wardens, and Traffic Light Controls at road intersections mainly to avoid traffic jams and to also reduce unnecessary delays at such intersections. However, Traffic Wardens are humans and so are easily prone to errors due to fatigue and are also easily affected by weather conditions like rain [2]. More so, at night, visualization is a serious hindrance to the operations of Traffic Wardens. Hence, a different approach is needed; the application of intelligent artifacts (Traffic Lights) to manage traffic flow in a more effective and efficient manner [5].

This intelligent approach leads to a relatively new research area called Intelligent Transportation System (ITS) which is basically concerned with the application of Information and Communication Technologies (ICT) to the planning and operation of transportation system. Traffic observation, control and real-time management are just few of the major components within future Intelligent Transportation Systems (ITS). It is widely accepted by the transportation community that ITS makes existing transportation facilities efficient, minimizing the need to build more infrastructure [2].

The main goals of Intelligent Transportation Systems include minimizing travel time, improving safety on our roads and public transport service. Such improvements are beneficial to health, economy, and the environment [6].

It is frequently observed in rapidly growing cities that traffic congestions and long queues at road intersections occur especially during peak hours. Vehicles moving through a network of several traffic signal-controlled intersections mostly experience very high travel-time as they have to stop at almost every intersection on the path to destinations. This inefficient progressive traffic flow, which is commonly known as the unattainable ‘green wave effects’, is mainly due to lack of coordination between adjacent traffic signal controls.

1.2 Statement of the Problem

Many researchers [7], [8], [9] proposed different applications of traffic controls that focus on the conventional set-ups whereby only the roads and directions with the heaviest loads get the preferential treatment of green wave but never considered a network of green waves because of its complexity and usability [10].

The focus on this research is to simulate a road network of four intersections and execute the green wave technology to minimize travel time. Any vehicle travelling along the green wave at an approximate velocity decided upon by the traffic engineers(progression speed) will see a progressive cascade of green lights at intersections. This reduction of travel times will thereby reduce Carbon monoxide and Nitrogen Oxides emissions from vehicles, reduce fuel consumption of vehicles, help pedestrians cross streets as vehicles travel in platoons, control the velocity of traffic in urban areas, and also reduce component wear of vehicles like brake-pads, tires, and hydraulic oil.

1.3 Traffic Controls

1.3.1 The Origin of Traffic Controls

The true origin of traffic control is unknown to us but historical evidence has shown that traffic problems emanated when main roads came into existence. Man has always had problems with roads filled with travelers[1]. Actually, some of the first strategies for traffic control were not a device but set of laws made by governments. For instance, in Rome during the days of Julius Caesar, the streets of Rome were so congested with chariots that the government made certain areas off limits to all commuters except those belonging to public officials and high-ranking citizens [11]. History also has it that traffic control that relates to a traffic light is the use of traffic cops to manage the flow of traffic on the London Bridge in 1722 [11]. The first traffic control device that was neither human nor an act of regulation appeared in 1868 in London outside the House of Parliament by John Peake Knight [12]. Ever since the world’s first traffic lights were set up, traffic lights control has been advancing in form and complexity [13].

1.3.2 Intersection Geometry

The overall traffic flow largely depends on the performance of the intersections on the path of the flow. Traffic intersections are complex locations on any highway. Conflicts at an intersection are different for different types of intersection [14]. For instance, for a typical four-legged intersection, there are thirty-two (32) different conflicts at the junction: - Through Movements have four (4) conflicts, competing left-turn and through movements have eight (8) conflicts, left turn movements have four (4) conflicts, between right turn and merging movements have four (4) conflicts, diverging movements also give four (4) conflicts, and pedestrians create eight (8) conflicts in all the four approaches. The intersection conflict is represented in Fig. 1.

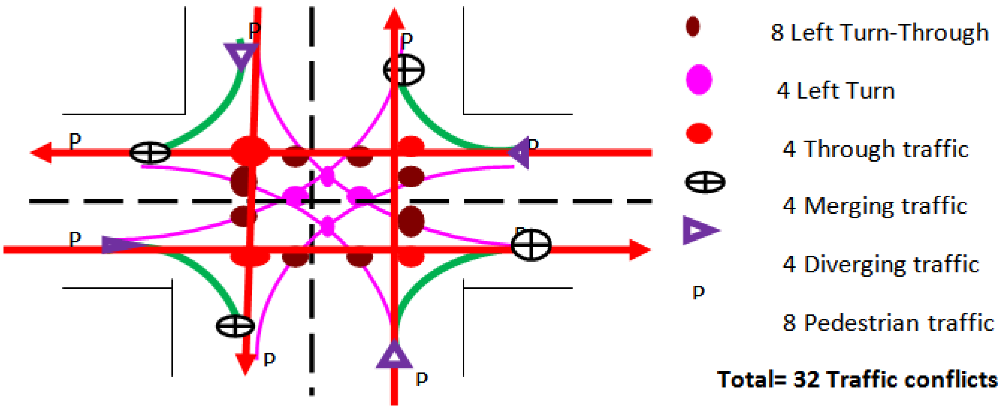

Figure 1: Diagram of Intersection Conflicts: Source: Mathew, 2014.

All approaches to resolve intersection conflicts barely optimize the sharing of time and space [14]. Therefore, the type of traffic control to be deployed depends on, but not limited to, the traffic volume, intersection geometry, and the importance of the road.

The control of traffic can be achieved at different levels; Passive control, Semi control, or Active control. In Passive Traffic Control, there is virtually no explicit control beyond the observation of the rules of the road. Traffic signs and markings mainly regulate movements. This Passive Traffic control is only effective where traffic volume is very low [15]. In Semi Traffic control or Partial traffic control, drivers are gently guided through traffic rotaries (Roundabouts) and Channels (traffic islands) to avoid conflicts. This approach is efficient only in low traffic volumes [15].

It is worthwhile to mention here that Passive, Semi traffic control types and Grade separated intersection (flyovers) are actually unsignalized traffic controls, while Traffic signal control is the only signalized traffic control. Active traffic control implies that the user is compelled to follow the time and space sharing of the traffic control agencies. This control type is characterized by very high traffic volumes and moving at high velocity. The Active traffic controls are of two types: Grade Separated Traffic Control (flyovers) and Traffic Signals [15].

Grade Separated traffic control (flyovers) allow the traffic to cross at different vertical levels. This control is done by sharing of space. The initial construction cost is very high but the road capacity is increased, and so they are only constructed on very important high velocity facilities like expressways.

Traffic Control using traffic signal is based on time sharing approach. At a given time and with the use of appropriate signals, certain traffic movements are restricted whereas certain other movements are permitted to pass through the intersection. The signals can operate at several modes; fixed time signals or actuated signals. In fixed time signals, the cycle time, phases and interval of each signal is fixed. On the other hand, actuated signals can respond to dynamic traffic situations, using vehicle detecting sensors.

1.3.3 Advances in Traffic Controls

History has it that traffic congestion and vehicular emissions have always been the destructive problems seeking the attention of man since the invention of internal combustion engine[16]. There are numerous developments of the evolution of traffic controls to date. The first intersection traffic control was the development of gas-powered manually turned semaphores by John Peake Knight in 1868 in London [17].

The electrification of urban areas led to the development and installation of the first electrically operated traffic signals in Cleveland, United States in 1914 [16]. They also said that in 1919, New York began converting from hand control semaphores to electromechanical controllers. This electromechanical traffic controller dominated the traffic signal system market from 1920s to 1970s. Cycle lengths were programmed by installing appropriate gears and the cycle was split into various intervals by inserting pins on a timing dial.

Progressively, the first computerized (Microprocessor-Based) traffic signal control system was installed in Toronto, Canada [5]. Development pace was relatively modest until 1970s when microprocessors became commonly available and software and hardware standardization efforts were first initiated. These efforts attracted significant follow-up ideas that have profoundly impacted the innovative practices and equipment used today [16].

Accordingly, vendors rushed into developing incompatible traffic signal devices and so frustrated the maintenance of the devices[4]. In 1989, standard specification commonly referred to as TS 1was drafted. In a somewhat parallel track to the NEMA developments, the California Department of Transportation (Caltrans) and the New York Department of Transportation (DOT) developed a specification designed to provide both standard connectors and portable software. The philosophy of this standard was somewhat different from the NEMA standard because it provided a precise specification for a generic traffic control microcomputer [13],[16]. Also, a structured approach to centralized traffic signal control called Urban Traffic Control Software (UTCS) was developed.

All the traffic controls have their signal timings either fixed (static) or actuated (dynamic)[3]. In fixed (Pre-Timed) traffic signal, the occurrence and duration of all timing intervals in all phases are predetermined [18]. In dynamic (Actuated) traffic signal, the controller uses input from detectors (sensors) to adjust signal timing and phasing within the limits set by the controller's programming. It can give more time to an intersection approach that is experiencing heavy traffic or shorten or even skip a phase that has little or no traffic waiting for a green light [19]. Actuated signals in general are not preferable because of the maintenance requirements and upkeep of the detection on the street [3].

1.3.4 Green Wave Traffic Controls

Coordination is defined as the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system [2]. If you've been lucky enough to catch all the green lights as you drive down a busy street, you may have been benefiting from intentional harmonization called a "green wave" [20]. Many large cities around the world, especially in Europe and the US, synchronize traffic lights on the busiest streets to create green waves. There are numerous factors used to determine whether coordination would be beneficial and therefore establishing coordination is easiest to justify when the intersections are in close proximity and when traffic volumes between the adjacent intersections are large[2].

When a green wave works as intended, all vehicles within the wave can drive through a sequence of green traffic lights at a certain speed without having to stop at the signals [9]. The timing of the lights can be controlled either by sensors or timers and can be set up for traffic in one direction or both directions [20]. Green waves have several benefits, such as allowing for higher traffic loads, reducing travel times, controlling traffic speed, reducing fuel consumption and emissions, and facilitating pedestrian traffic.

When traffic gets backed up for some reasons, "green wave breakdown" occurs [2]. The biggest disadvantage of green waves is over-saturation; a situation where the queue of vehicles in a green wave grows in size until it becomes too large and some of the vehicles cannot reach the green lights in time and must stop. The physics of the breakdown of a green wave in a city is revealed. Kerner wrote “We have found that there are two regions of flow rates in the green wave within which the green wave breakdown is possible. In the region of larger flow rates bounded by the maximum capacity and threshold flow rate, a time-delayed spontaneous green wave breakdown occurs with some probability during a given observation time [5]. In the region of smaller flow rates bounded by the threshold flow rate and minimum capacity, only an induced green wave breakdown is possible”[5].

The coordination strategies should follow the policies and resulting objectives for signal timing. Once these policies and objectives are defined, performance measures can be established to determine whether the application is beneficial. Various performance measures can be used to evaluate signal coordination. Evaluation methods include reduction in travel time of vehicles and in the number of stops of the vehicles. Three fundamental parameters distinguish a coordinated signal system: cycle length, split and offset. These settings are necessary inputs for coordination [15].

The guide adopted in the selection of coordination settings is based on established practices and techniques. These settings include Cycle length, Split Distribution and Offset Optimization.

a. Cycle Length

Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of green for one approach till the next time the green starts. It is denoted by C:

$$C = (1.5 * L + 5)/(1.0 - SYi)$$

Where:
C is the optimum Cycle length in seconds
L is the lost time in seconds
*SYi*is the critical lane volume each phase/saturated flow
From traffic count conducted during the research, the following values were obtained: -
Lost time (Time of perception/Reaction time), L=1.5s
The Sum of ratios, SYi = 0.9396.
Therefore, the Cycle length is computed as 120 seconds.

b. Split Distribution

Within a cycle, splits are the portion of time allocated to each phase at an intersection. These are calculated based on the intersection phasing and expected demand. Splits can be expressed either in percentages of the cycle or in seconds. Split typically include the yellow period, the all-red period, and the green period. For implementation in a signal controller, the sum of the phase splits must be equal to (or less than) the cycle length. In this research of Cycle length of 120 seconds, each of the four phases has 30 seconds for Actual Green interval, Lost time and Yellow interval. To avoid "Dilemma Zone", standard yellow time for various velocity limits are made [19]. In this research work of progression speed of 60KPH (16.67m/s), the yellow interval 4.5 seconds. The Green interval for each phase = Phase Totaltime - (Yellow interval + Lost time) = 30- (4.5+1.5)= 24s. The All-Red interval = 120 -30 = 90 seconds.

c. Offset Determination

The offset is the time from when the signal turns green until the succeeding signal turns green. When the offset is zero, then the lights would turn green at the same time.

t_{ideal}= D/S

Where:

t_{ideal} is the ideal Offset in seconds

D is the block distance in seconds

S is the progression speed in m per second

1.3.5 Simulation of Green Wave Traffic Controls

"No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists in replacing the part of the universe under consideration by a model of similar but simpler structure. Models, intellectual on the one hand or materials on the other, are thus central necessities of scientific procedures"[21].

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process [22]. The model represents the system itself, whereas the simulation represents the operation of the system over time.

Traffic simulation or the simulation of transportation systems as the mathematical modeling of transportation systems (example, freeway junctions, arterial routes, roundabouts, and downtown grid systems) through the application of computer software to better help plan, design and operate transportation systems [18]. Simulation of transportation systems started over forty years ago and is an important area of discipline in traffic engineering and transportation planning today. Simulation in transportation is important because it can study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment and can produce attractive visual demonstrations of present and future scenarios.

To understand simulation, it is important to understand the concept of system state, which is a set of variables that contains enough information to describe the evolution of the system over time. System state can either be discrete or continuous. Traffic simulation models are classified according to discrete and continuous time, state, and space [23].

II. METHODOLOGY

2.1 Modeling of The Road Network

The layout of the road network is a two-dimensional approach that covers a rectangular area of 720X420 pixels. Four single carriageways intersect thereby forming the four intersections (junctions); JW, JX, JY, JZ with JW on Top-Left, JX on Bottom-Left, JY on Bottom-Right, and JZ on Top-Right. By this design, entry points into the network through intersection JW will be A and H, through intersection JX will be B and C, through intersection JY will be D and E, and through intersection JZ will be F and G. Consequently, the exit points from the network through intersection JW will be I and P, through intersection JX will be J and K, through intersection JY will be L and M, and through intersection JZ will be N and O. Hence, the entry points (A, B, C, D, E, F, G, H) are design areas where vehicles can originate, while the exit points (I, J, K, L, M, N, O, P) are design areas for destinations of the vehicles. The yellow lines across the lanes approaching intersections are indicating the beginning of the minimum safe stopping distance which will be used to avoid "dilemma zone".

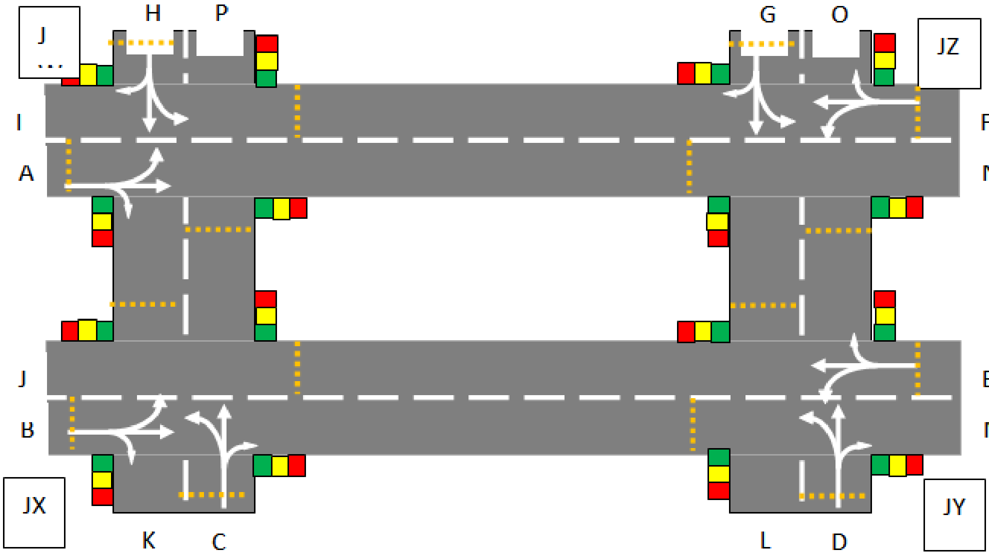

Figure 2:Intersection Diagram at Central Area Abuja-Nigeria

With reference to the centers of the roads, the approximate distances between adjacent intersections are: -

Distance between Intersections JW↔JX = JZ↔JY = 250meters

Distance between Intersections JW↔JZ = JX↔JY = 130meters

Distance between points H↔I = B↔K = D↔M = F↔O = 10meters

2.2 Modeling of Traffic Controls

There are four intersections (Junctions) to be considered in the research. Which are: - Junction W (JW), Junction X (JX), Junction Y (JY), and Junction Z (JZ).And at each intersection, there are four traffic lights. Therefore, there are sixteen (16) traffic lights in all for this road network, which are: -

JW1, JW2, JW3, JW4
JX1, JX2, JX3, JX4
JY1, JY2, JY3, JY4
JZ1, JZ2, JZ3, JZ4

Although, there are different phase designs in a cross intersection, however the following phase design in *Figure 4* will be used.

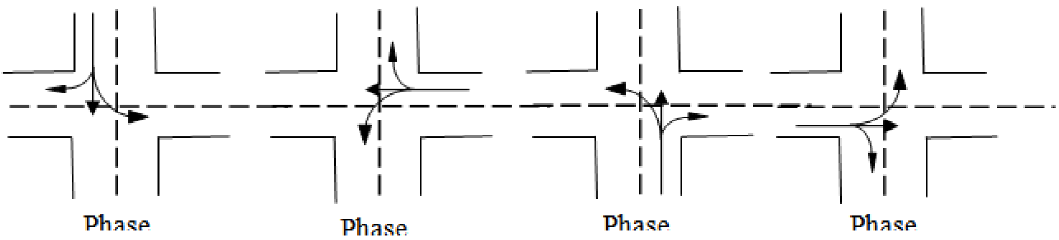

Figure 3:Four Phase design diagram

3.2.3 Design Without Green Wave

In this design, all the intersections have the same phase controller diagram, signal group and the relationship between Phase and Signal Group as indicated by *Figures* 5, 6 and 7.

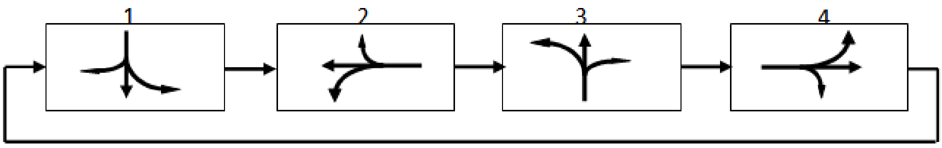

Figure 4*: Four Phase Controller Diagram for all Intersections*

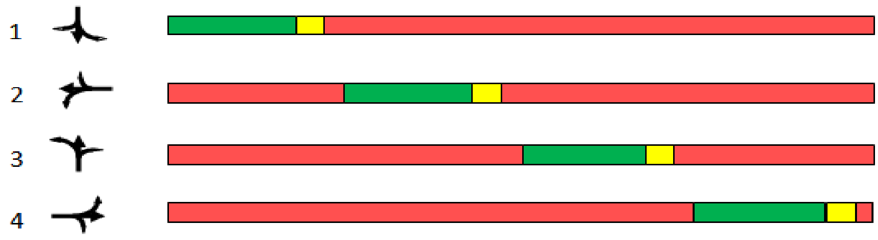

Figure 5: Signal Group Diagram for all Intersections

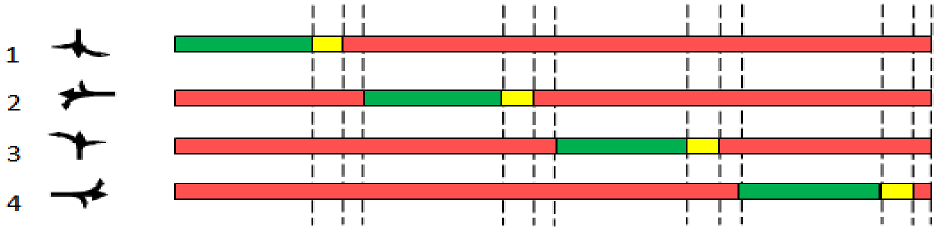

Figure 6:Relation between Phase and Signal group for all Intersections

3.2.4 Design With Green Wave

At each intersection, coordinated phases are designated to maintain the relationship between adjacent intersections. In this design, all the different intersections have their unique phase designs and release matrices as indicated in *Figures* 8, 9, 10 and 11, and equations 9, 10, 11 and 12 respectively. It is worth noting that intersection JW is considered as the reference point where the Master Clock is measured. In this design, the Master clock is the System's clock that is running the simulation.

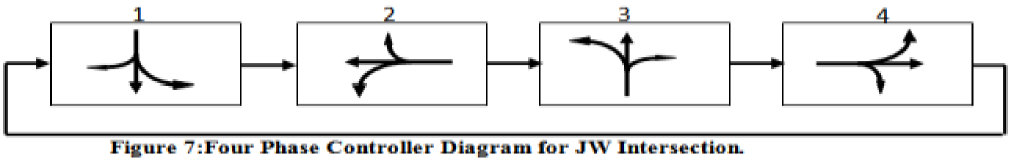

Figure 7:Four Phase Controller Diagram for JW Intersection.

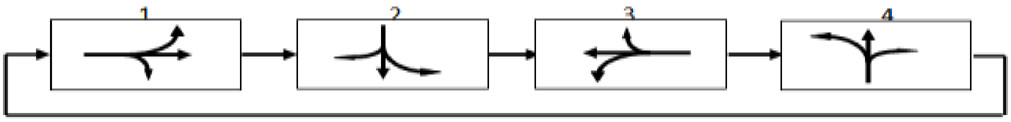

Figure 8: Four Phase Controller Diagram for Intersection JX.

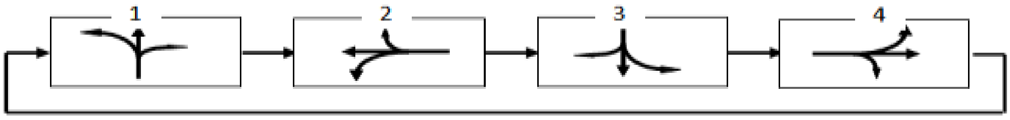

Figure 9: Four Phase Controller Diagram for Intersection JY.

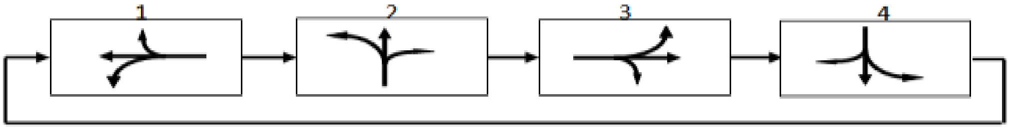

Figure 10: Four Phase Controller Diagram for Intersection JZ.

2.3 Modeling of Vehicles

On the road network layout, vehicles are designed to have the following attributes:

i. Origin and destination: - Rectangular boxes will be modeled as vehicles from entry points of the network. The template will require from the user the specifications of the number of vehicles to produce, the origin from the entry points, and the destination from the exit points.

ii. Velocity and Colour: The velocity and colour of each vehicle will be specified by the user.
iii. Determine path from origin to destination: To achieve minimal delays, the shortest path from the specified origins and destinations of the vehicles is determined and attributed to each vehicle.
iv. Respond to bends: Using the assigned path from origin to destination, the vehicle will detect intersection and change directions based on coordinates of the two-dimensional geometry.
v. Respond to traffic light control: At the minimum safe stopping distance (Marked with broken yellow lines on the layout), the vehicle checks the status of the traffic ahead to determine whether to proceed safely into the intersection or stop by the intersection until the status of the traffic light indicates green to advance.
vi. Start and stop timer: For coordination to be efficient, there must be a Master Clock where all timings at all intersections will synchronize. In this project, the systems clock will be used. That is, every vehicle reads the time of its generation from the entry point to the time of its exit at its destination.

2.4 Design of Result Evaluations

Without Green Wave, a set of vehicles will be generated at different origins and terminating at different destinations, the timings (start-time & stop at destination time) of each vehicle is captured. The difference between start-time and stop-time gives the time taken for the vehicle to move from origin to destination (travel times) without the green wave. Then running the same set of vehicles with the same origins and destinations this time with Green Wave and generate their travel times. The values obtained will be analyzed to depict the efficiency of using green wave.

III. RESULTS

3.1 Presentation of Results

In the design and execution of the simulation, certain assumptions and policies are adopted. One of the policies is that there is no U-turn at intersections. Another issue is that each vehicle moves at its constant velocity as acceleration and deceleration abilities are actually not modeled. The vehicles modeled are of the same length 30 pixels that modeled a standard car length of 180 inches (4.572 m). The results are obtained by varying the variables (Distance traveled and the number of intersections on the path, Velocity of vehicles, and Traffic volume) and executing the simulation on the two platforms (without Green Wave Technology and With Green Wave Technology).

3.2 Travel Time Comparison

When the simulation was executed on the two platforms (with Green Wave and without Green Wave) using different combinations of specifications on the vehicles, different results of the travel times were obtained. These variations were specifically made on the distances when the sources and destinations of vehicles, the velocities of the vehicles were also altered, and the traffic volumes were also varied from initial four vehicles in the network to eight vehicles and then to sixteen vehicles.

3.2.1 Effects of Distance

When the distances were varied, there is noticeable difference in the travel times when the network was on Green Wave, and without Green Wave as shown in Table 1.

VEH	Vehicle
ORIGIN	Origin of vehicle
DEST	Destination of vehicle
DIST	Distance traveled by vehicle
VEL	Velocity of vehicle in meters/second
INT	Number of intersections on path
TTWGW	Travel time without green wave in seconds
TTGW	Travel time on green wave in seconds
TTReq	Travel time required in ideal case

Table 1: Case of varying distance on TTWGW and TTGW

	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 1	Car 1	F	O	10	16.67	1	9	5	0.6
	Car 2	A	J	130	16.67	2	22	8	7.8
	Car 3	H	O	250	16.67	2	33	22	15
	Car 4	H	L	380	16.67	3	55	39	22.8
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 2	Car 1	H	I	10	16.67	1	7	6	0.6
	Car 2	C	P	130	16.67	2	20	19	7.8
	Car 3	G	P	250	16.67	2	32	22	15
	Car 4	G	K	380	16.67	3	51	44	22.8
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 3	Car 1	B	K	10	16.67	1	16	6	0.6
	Car 2	D	O	130	16.67	2	9	9	7.8
	Car 3	F	I	250	16.67	2	15	15	15.0
	Car 4	H	M	380	16.67	3	48	31	22.8
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 4	Car 1	D	M	10	16.67	1	1	1	0.6
	Car 2	G	L	130	16.67	2	14	14	7.8
	Car 3	A	N	250	16.67	2	15	15	15.0
	Car 4	C	O	380	16.67	3	48	35	22.8

3.2.2 Effects of Vehicle Velocity

In the same manner, the velocities of the vehicles were varied and the following results and graphical representation in Table 2 of the relationships were obtained. In this case, one graph can combine the four cases of different velocities.

Table 2: Case of varied Vehicle Velocity on TTWGW and TTGW

case	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 1	Car 1	F	O	10	16.67	1	1	1	0.6
	Car 2	A	J	130	16.67	2	22	8	7.8
	Car 3	H	O	250	16.67	2	33	22	15.0
	Car 4	D	P	380	16.67	3	32	24	22.8
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 2	Car 1	F	O	10	33.33	1	1	1	0.3
	Car 2	A	J	130	33.33	2	4	4	3.9
	Car 3	H	O	250	33.33	2	13	13	7.5
	Car 4	D	P	380	33.33	3	13	12	11.4
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 3	Car 1	F	O	10	50.00	1	1	1	0.2
	Car 2	A	J	130	50.00	2	3	3	2.6
	Car 3	H	O	250	50.00	2	11	11	5.0
	Car 4	D	P	380	50.00	3	11	11	7.6
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 4	Car 1	F	O	10	66.67	1	1	1	0.2
	Car 2	A	J	130	66.67	2	3	3	2.0
	Car 3	H	O	250	66.67	2	11	9	3.8
	Car 4	D	P	380	66.67	3	11	11	5.7

3.2.3 Effects of Traffic Volume

In this experiment, the traffic volumes of the road network were varied and the following results were obtained as shown in Table 3.

Table 3: Case of varied Traffic Volume on TTWGW and TTGW

CASE	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 1	Car 1	F	O	10	16.67	1	9	5	0.6
	Car 2	A	J	130	16.67	2	22	8	7.8
	Car 3	H	O	250	16.67	2	33	22	15
	Car 4	H	L	380	16.67	3	55	39	22.8
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 2	Car 1	F	O	10	16.67	1	1	1	0.6
	Car 2	H	I	10	16.67	1	6	6	0.6
	Car 3	A	J	130	16.67	2	22	8	7.8
	Car 4	C	P	130	16.67	2	19	23	7.8
	Car 5	D	K	250	16.67	2	28	18	15
	Car 6	B	M	250	16.67	2	30	40	15
	Car 7	E	I	380	16.67	3	53	29	22.8
	Car 8	G	J	380	16.67	3	42	53	22.8
	VEH	ORIGIN	DEST	DIST	VEL	INT	TTWGW	TTGW	TTReq
CASE 3	Car 1	H	I	10	16.67	1	8	6	0.6
	Car 2	B	K	10	16.67	1	19	31	0.6
	Car 3	D	M	10	16.67	1	2	1	0.6
	Car 4	F	O	10	16.67	1	3	1	0.6
	Car 5	H	K	130	16.67	2	37	9	7.8
	Car 6	C	P	130	16.67	2	41	24	7.8
	Car 7	G	L	130	16.67	2	36	14	7.8
	Car 8	D	O	130	16.67	2	27	9	7.8
	Car 9	A	N	250	16.67	2	36	15	15
	Car 10	F	I	250	16.67	2	33	17	15
	Car 11	B	M	250	16.67	2	32	17	15
	Car 12	E	J	250	16.67	2	52	20	15
	Car 13	A	L	380	16.67	3	62	48	22.8
	Car 14	E	P	380	16.67	3	67	27	22.8
	Car 15	F	K	380	16.67	3	71	45	22.8
	Car 16	C	N	380	16.67	3	71	34	22.8

Table 4: t-test when Distance Varied

				Confidence interval	
variable	df	t-value	p-value	LCL	UCL
Time diff	15	4.0376	0.001074	3.068653	9.931347

Table 5: ANOVA When Distance Varied

variable	df	Sum sq	Mean sq	t-value	p-value
Distance	1	184.34	184.344	5.8969	0.02924
Residual	14	437.66	31.261		

Table 6: t-test when Velocity Varied

				Confidence interval	
variable	df	t-value	p-value	LCL	UCL
Time diff	15	1.9959	0.06443	-0.1528096	4.6528096

Table 7: ANOVA When Velocity Varied

variable	df	Sum sq	Mean sq	t-value	p-value
Distance	1	8.04	8.0396	0.371	0.548
Residual	14	296.96	21.2115		

Table 8: t-test when Traffic Volume Varied

variable	df	t-value	p-value	Confidence interval LCL	Confidence interval UCL
Time diff	27	4.7169	6.519×10^{-05}	7.001962	17.783752

Table 9: ANOVA When Traffic Volume Varied

variable	df	Sum sq	Mean sq	t-value	p-value
Distance	1	1333.0	1332.75	8.919	0.006082
Residual	26	3885.7	149.45		

IV. DISCUSSION

The travel times in seconds with green wave and without green wave were compared using statistical software called R-Package version 3.1.3.

4.1 Effects on Distance

The distances were varied while the traffic volume and velocity were fixed. The results were compared using the t-test where the result reveals that there is significant difference in travel time between distances covered with green wave and without green wave, with a p-value of 0.001074 as shown in Table 4.The result reveals that when green wave is used, there is substantially low travel time taken to cover a distance when velocity and traffic volume are fixed and distance varied.

Also, when the difference in travel time taken using the TTWGW and TTGW reveals that the distance covered has effect on time taken using the green wave with the lowest distance having the lowest difference with a p-value of 0.02924 as shown in Table 5.

4.2 Effects of Velocity

The time taken using green wave and without green wave were compared when the velocities of the vehicles were varied, and the distance and traffic volume were fixed. The result reveals that the difference was not significant at 5% level but rather at 10% level with a p-value of 0.06443 as shown in Table 6.

Further subjecting the difference in time taken when velocity varied was analyzed and the result reveals that there is no any significant difference in time when velocity is varied. This is shown in Table 7.

4.3 Effects of Traffic Volume

Similarly, the traffic volumes were varied while velocity and distance were fixed. The result indicates that there is significant difference in time taken, with a p-value of 6.519×10^{-05} (0.0000 to four decimal places). This is shown in Table 8.

The differences in travel times were also subjected to analysis of variance when traffic volume varied. The result indicates that there is significant difference at 1% level with p-value of 0.006082. This shows that there is difference in travel time when green wave is used and traffic volume varied. This is shown in Table 9.

V. CONCLUSION

Conclusion

Results obtained from execution of the simulation were tabulated, graphically represented and then used the statistical software called R-Package version 3.1.3 to analyze the results. Broadly speaking, the analysis shows that using green wave in the road network significantly reduce the travel time of vehicles compared with the situation of not using green wave.

The simulation results demonstrate that green wave implementation in the intersections in the Central Business Area, Abuja- Nigeria has a significant benefit to people and especially motorists in this part of the world. A general conclusion to be drawn is that progressive traffic flow in signalized intersections is efficiently achievable.

The simulation of the green wave automobile traffic control system is user friendly as the execution template/user interface is interactive. And being a Java program, the simulation program is quite portable, scalable and runs very fast on most systems.

The researchers have successfully used the Object-Oriented Design approach to achieve the implementation of this simulation. From the design of the traffic road network, the traffic signal controls, the design and simulation of the vehicles are all approaches of the Object-Oriented Design and Programming.

The researchers earnestly recommend the implementation of green wave on road networks that are signalized as this study has indicated its applications to be significantly beneficial to motorists in terms of reduced travel times, to the environment in terms of long emission of pollutants from vehicles, and to the economy of our nation in terms of fuel consumption during accelerations & decelerations at intersections, wearing out of brake pads and brake fluids.

More so, in the course of this study, the researchers came to terms with the fact that current traffic models use a mixture of empirical and theoretical techniques. This issue calls for more research work to bring up more traffic models that consider networks of traffic controls.

The implementation of this research on coordination of traffic control opens scholarly research areas that pertain to coordination using technologies like Local Area Network (LAN). In this study, synchronization of the traffic controls is achieved, which has a downside; whenever anyone of the traffic controls goes down then the synchronization is interrupted and so must be reset each time such a down time is experienced.

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