An Efficient Pervasive Road Traffic Management System

Dr. Nlerum Promise A.
Department of Computer Science and Informatics, Federal University Otuoke, Bayelsa State, Nigeria.

Dr. Friday Onuodu E.
Department of Computer Science, University of Port Harcourt, Choba, Rivers State, Nigeria.

Abstract – Congestion of vehicular traffic within urban areas is a problem experienced worldwide. It has adverse effects on people quality of life due to delays, accidents and environmental pollution. One way of eliminating the problem is to increase the capacity of existing roadways by addition of lanes. However, this is greatly hampered by lack of space, resources or due to environmental issues and sometimes politics. This leaves the relevant authorities with one major option, that of enhancing the utilization of existing infrastructure by employing better traffic management and operations strategies. For effective traffic management and control, we have deployed a pervasive computing infrastructure in conjunction with a microscopic traffic model to monitor road traffic situation with a view to proffering solutions to the ever challenging problem of congestion and vehicular traffic on our roads. In this paper, we have applied Microsoft Visual Basic and Mathematica software for modeling and simulation of the case study. This combination presents a powerful interactive visual modeling and simulation tool and is principally employed for creating animated and dynamic models. For compatibility reasons, we employed Microsoft Database Access for the backend data. This way, efficient road-traffic-users' database can be captured for proper identification and capturing.

Index Terms – Pervasive Computing, Microscopic Traffic model. Mathematica.

1. INTRODUCTION

Computer scientists approach the study of traffic from a modeling perspective. By creating accurate simulations of traffic systems, computer scientists allow engineers and city planners to quickly test new ideas. Simulations can determine how a proposed change in infrastructure will affect traffic before any construction is begun. Simulation is even used in video games to provide realistic traffic flow as a tool to immerse the player in a virtual world.

Urban traffic signal control is an important element of the safety for both pedestrians and vehicles when crossing an intersection or other paths. The time between different flows is controlled by traffic signals which can lead to the flow conflicts and disobedience to traffic rules and regulation. This was the first reason for the invention of traffic signal in the early 1900s, Wen, (2008). An urban traffic signal control system is a complex system characterized by randomness, burst, and uncertainty, Boillot, et al (2006). Utilizing a dependable model that can reflect the behavior of traffic control system is very important to realize traffic signal real-time control and track offenders. Traffic control systems reduce as much as possible the delay by vehicles tripping by a network of intersections and Boillot, et al (2006). By utilizing a suitable control policy, a suitably designed urban traffic signal control can decrease problems like vehicular congestion, stop delay, air and noise pollution, fuel consumption, discomfort and stress. Ultimately, an automated traffic monitoring system can report road traffic offenders and establish appropriate punishment in form of fines for traffic violators.

Congestion of vehicular traffic within urban areas is a problem experienced worldwide. It has adverse effects on people quality of life due to delays, accidents and environmental pollution. It is the major cause that leads to the unreasonable and reckless attitude of drivers on our roads. One way of eliminating the problem is to increase the capacity of existing roadways by addition of lanes. However, this is greatly hampered by lack of space, resources or due to environmental issues and sometimes politics. This leaves the relevant authorities with one major option, that of enhancing the utilization of existing infrastructure by employing better traffic management and operations strategies; such strategies to manage traffic congestion and curb the spate of indecent driving by road traffic offenders. For effective traffic management and control of our roads, proper understanding of road traffic models is needed. This can be done through appropriate study and simulation.

2. RELATED WORK

Since its beginning, simulation has been applied to various sectors, such as manufacturing, services, defense, healthcare, and public services. Simulation is recognized as the second mainly used technical instrument in the field of operations management Lee, et al (2004). Traffic simulation has developed into a productive instrument to encounter the essential needs of transportation modeling and examination. Simulation has the capability in modeling the complex nature of an actual transportation system Cicortas and Somosi (2005). By creating a computer model and moving it through time, simulation is generally delineated as the dynamic and powerful representation of the process of the actual world performed.

In this paper, we have applied Microsoft Visual Basic and Mathematica software for modeling and simulation of the case study. This combination presents a powerful interactive visual modeling and simulation tool and is principally employed for creating animated and dynamic models. For compatibility reasons, we employed Microsoft Database Access for the backend data. This way, efficient road traffic users' database can be captured for proper identification and capturing.

2.0. Basic Traffic Simulation Models

Traffic simulation has proven to be a useful and cost effective approach for providing real time traffic information in support of incident discovery and incident analysis, Lopez-Neri, et al (2008). Traffic simulation systems and models are apportioned to various different classifications. One of the fundamental classifications is the division between macroscopic, microscopic and mesoscopic models Lopez-Neri, et al (2008). According to Lopez-Neri, et al (2009), microscopic models predict the mood of single and individual vehicles both continuous and discrete types like individual vehicle speeds and locations.

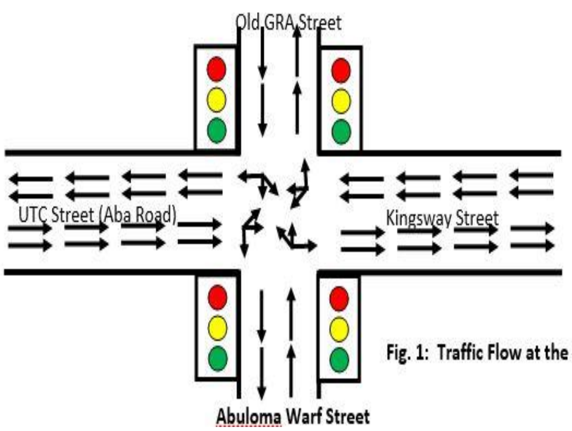

Fig. 1: Traffic Flow at the Intersection

But macroscopic models make ready an extensive depiction of the traffic flow situations while mesoscopic models include the mixed aspects of both microscopic and macroscopic models. Therefore, macroscopic models can only depict entities and their action or communication with low loyalty.

Despite the fact that mesoscopic model with combined loyalty represent entities at a proportionately high level as compared to the macroscopic one, it is quite at a large amount lower in level, in depicting their actions and interactions as compared to microscopic model. Between the different kinds of aforementioned traffic simulation techniques, microscopic simulation techniques are the most suitable for simulating actual traffic conditions and examining control policies, which eventually allows appropriate sanctions to be meted out to traffic violators. In the sections that follow, we develop an efficient microscopic traffic model to capture road traffic user behavior and track his activities using a suitable model. We also present some simulation results that explain the behavior of the model.

3. PROPOSED MODELING

Case Study

Port Harcourt is one of the main cities in the southern part of Nigeria. In this dissertation, discrete event simulation has been applied to provide a simulation model of an isolated traffic intersection. We concentrate on one of the main intersections of the urban traffic system of Port Harcourt. As depicted in Figure 1, the traffic system consists of UTC, Abuloma Warf, Old GRA and Kingsway streets. UTC Junction is the main street of the traffic system. Cars crossing the intersection have the options to go straight or turn to either of the side roads. The intersection traffic light control uses a three phase policy consisting green, yellow, and red coding lights. If the light is green, a waiting vehicle can go straight or turn to left or right, depending only on the driver's decision.

As mentioned earlier, the microscopic traffic model has been used to model road traffic users, since it presents a subjective scenario of road users.

Microscopic models attempt to model the motion of individual vehicles within a system. They are typically functions of position, velocity, and acceleration. Microscopic models are typically created using ordinary differential equations, with each vehicle having its own equation. Because the behavior of these models is usually dictated by a lead vehicle, they are termed "car-following" models. Figure 2 demonstrates how microscopic models number vehicles in car-following situations.

Microscopic models were developed to try to emulate the way a human behaves in traffic situations. To accomplish this, the models contain different driving states to describe typical driving responses encountered. The first driving state is the Free Traffic state. This situation is encountered with low vehicle density, and individual vehicles can accelerate to their desired velocity. No lead vehicle is present to influence vehicle position, velocity, or acceleration. The second driving state is the Following state. The Following state is encountered in everyday traffic, with medium to high vehicle density. In this state, a vehicle's velocity and acceleration is largely determined by the vehicle in front of it. A driver attempts to maintain a minimum and maximum vehicle gap (or time gap) between themselves and the lead vehicle.

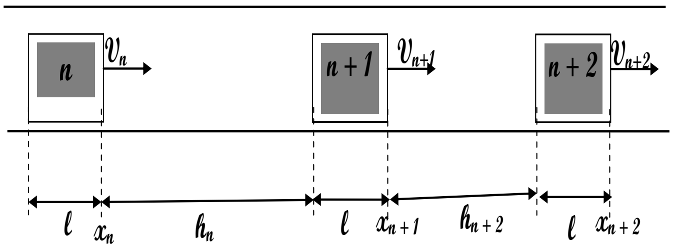

Figure 2

The final driving state is the Braking state. This state is sometimes referred to as an Emergency Response. This state becomes active if the current vehicle is approaching a stopped or significantly slower vehicle. The driver will attempt to stop using various degrees of braking force in an attempt to avoid colliding with the object in front of it.

The most basic Microscopic Model used is an enhanced Gipp's Model. Developed in the 1970's, the model uses driving states to model traffic flow. The model is given by:

$$\ddot{x}_n(t) = C\,\frac{\dot{x}_n(t) - \dot{x}_{n-1}(t)}{x_n(t) - x_{n-1}(t)} \qquad (1)$$

With the nth car location denoted, $x_n(t)$. This shows that the acceleration of the current car $\ddot{x}_n(t)$ depends on the speed and position of the car in front, with C being a sensitivity parameter.

One disadvantage of the earlier models was that certain parameters had unrealistic parameters or behaviors.

As an example, they may allow unrealistic breaking behavior beyond the capabilities of physical vehicles. Modern models attempt to resolve these issues by utilizing multiple sensitivity parameters or other methods.

A current, state-of-the-art model is the Intelligent Driver Model (IDM). This equation was developed by Treiber, Hennecke, and Helbing to improve on previous models, and was published in 2000. The model contains an acceleration strategy with a braking strategy to cover the three driving states above. The IDM model is given by:

$$v_{IDM}(s, v, \Delta v) = a\left[1 - \left(\frac{v}{v_0}\right)^{\partial} - \left(\frac{s^*(v,\ \Delta v)}{s}\right)^2\right] \qquad (2)$$

Where

$$s^*(v,\ \Delta v) = s_0 + vT + \frac{v\nabla v}{2\sqrt{ab}} \qquad (3)$$

The S^* term below the main function is an expansion of s^* in the numerator of the main function. We can see that the IDM model is an acceleration function of vehicle gap s, velocity v, and velocity difference, Δv. Other parameters with their typical values are given below:

Table 1: Traffic Parameters and values

Parameter	*Typical Value*
Desired velocity v_0	*120km/h*
Safe time headway T	*1.60s*
Maximum acceleration a	*0.73m/s²*
Desired deceleration b	*1.67m/s²*
Acceleration exponent ∂	*4*
Jam distance s_0	*2m*
Jam distance (s_1)	*0m*
Vehicle length $l = {}^1/_{\rho_{max}}$	*5m*

The free traffic state of equation (2) dominates when s is very large, causing the interaction term to become negligible. The free traffic term is then:

$$\dot{v}_{free}(v) = a\left[1 - \left(\frac{v}{v_0}\right)^{\partial}\right] \qquad (4)$$

It is easily seen that as $v \rightarrow v_0$ the acceleration $\dot{v}_{free}(v) \rightarrow 0$. This models the tendency for a driver to gradually decrease their acceleration as they approach their desired velocity, v_0. The braking or interaction term of equation (2) governs the braking and following driving states. The braking term is given by:

$$\dot{v}_{brake}(s, v, \Delta v) = -a\left(\frac{s^*}{s}\right)^2 \qquad 5$$

Where

$$s^*(v, \Delta v) = s_0 + vT + \left(\frac{v,\ \Delta v}{2\sqrt{ab}}\right) \qquad 6$$

In normal driving conditions, the vT term dominates. The vT term attempts to maintain a specific time gap T from the vehicle being followed. The $\left(\frac{v,\ \Delta v}{2\sqrt{ab}}\right)$ term dominates when approaching an object at a high rate of speed. The model attempts to brake within the limit b, but will exceed b's value if required to avoid a collision.

4. SPACE GAPS AS AN IMPETUS TO TRAFFIC BREAKDOWN

Many traffic operations such as lane-changes, merging of vehicles at on-ramps, and crossing at intersections depend on the availability of space gaps (i.e. the distance between the front bumper and the rear bumper of two vehicles following one another) in traffic flow. Sullivan and Troutbeck (2006) showed that space gaps are crucial in the analysis of non-signalised intersections and traffic circles (roundabouts). Moreover, the characteristics of space gaps, is quite relevant in the study of optimal traffic signal control.

We remark that the distribution of space gaps has a significant effect on platoon formation and delays. Actually, space gaps are a basic ingredient in the Acceleration Time Delay model of three-phase traffic flow developed by

Kerner and Klenov (2006). According to Kerner, (2009), the nature of traffic breakdown is explained by a competition of two opposing tendencies i.e. the tendency towards synchronized flow due to vehicle deceleration to adapt to the speed of the leading vehicle and the tendency towards the initial free flow due to vehicle acceleration after relieving its constraints through a lane-change manoeuvre to a faster lane. The tendency associated with speed adaptation effect can be described using space gaps as follows: whenever a vehicle approaches a slower preceding vehicle and cannot overtake, it decelerates to adapt its speed to the speed of the preceding vehicle at any space gap within the space gap range.

$$h_{safe}(u) \leq h \leq h_s(u) \qquad (7)$$

Without caring, what is the precise space gap to the preceding vehicle, i.e., at a given steady speed in synchronized flow; a driver makes an arbitrary choice of a space gap from a multitude of space gaps within the range given above.

$h_s(u)$, is known as the synchronization gap and is given by:

$$h_s(u) = uT_s; \quad T_s = T_0\left(1 - 0.95\left(\frac{u}{v_{max}}\right)^2\right) \quad (8)$$

Whereas, $h_{safe}(u)$ is the safe gap and expressed in terms of the safe time gap as;

$$h_{safe}(u) = uT_{safe} \qquad (9)$$

Where u is the average velocity, v_{max} is the maximum velocity and T_0, T_{safe} are constants. The second tendency that causes traffic breakdown at bottlenecks i.e. the one due to acceleration can be described using space gaps by considering vehicle motion on a multi-lane road occurring under the condition given by equation 7 and assuming that later the vehicle can pass the slow moving preceding vehicle by performing a lane-change maneuver to a faster lane and accelerating. Noting that at any given density, the probability of changing lanes is greater in free flow than in synchronized flow and that the steady states of synchronized flow cover a 2D-region in the flow density plane, we deduce that the probability of lane-changes should be modeled in such a way that it exhibits a discontinuous character i.e. a drop in lane-change probabilities when free flow transforms into synchronized flow.

5. THE NUMERICS AND RESULTS

Table 2 and 3 show the relationship among traffic users,' average velocity and the synchronization gaps. A plot of average velocity against synchronization gap shows that average velocity is directly proportional to the synchronization gap. This demonstrates that road users are very cautious of the safe distance between vehicles. The tables and graphs are presented below.

Table 2: Parameter values and results

Average Velocity u	*19*	*16*	*11*	*21*	*24*	*13*
Maximum Velocity v_{max}	*118*	*117*	*122*	*122*	*119*	*119*
T_o	*1.2*	*1.2*	*1.2*	*1.2*	*1.2*	*1.2*
T_{safe}	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*
Synchronization gap $h_s(u)$	***22.24***	***18.86***	***13.10***	***24.49***	***27.69***	***15.42***

Table 3: Parameter values and results

Average Velocity u	*15*	*14*	*16*	*23*	*19*	*10*
Maximum Velocity v_{max}	*122*	*117*	*124*	*117*	*120*	*115*
T_o	*1.2*	*1.2*	*1.2*	*1.2*	*1.2*	*1.2*
T_{safe}	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*
Synchronization gap $h_s(u)$	*17.74*	*16.57*	*18.90*	*26.59*	*22.26*	*11.91*

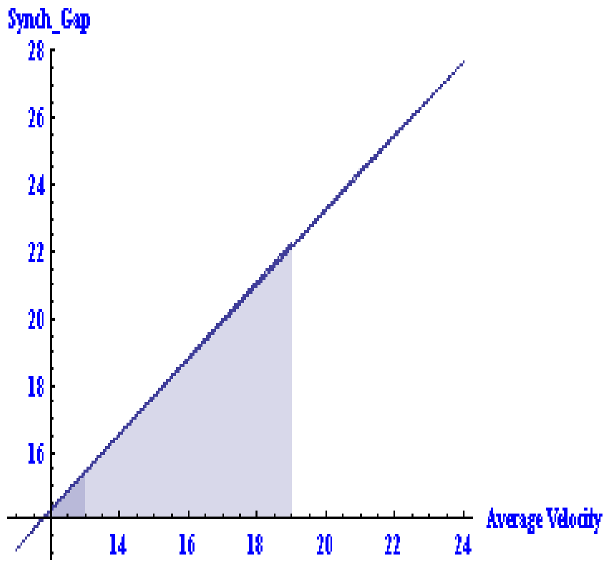

Fig. 3: Graph of Synchronization gap against Average velocity

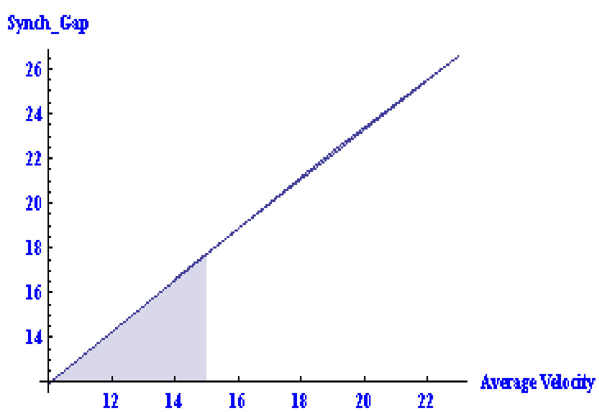

Fig. 4 Graph of Synchronization gap against Average velocity

6. CONCLUSION

Current applications of pervasive microscopic traffic models are only limited by the imagination. Traffic congestion is a continuing problem with no clear answer.

Pervasive traffic models are being used in many ways to try to find solutions to the congestion problem. Many algorithms are being used in technology known as adaptivecruise-control. By utilizing various sensors, a vehicle equipped with an adaptivecruise-control system can detect the velocity of lead vehicles. This allows the car to cruise at a set velocity until it encounters a slower vehicle. The car will then dynamically adapt its speed to match that of the slower vehicle automatically.

Fleets of vehicles with this technology are being studied to determine if adaptivecruise-control can increase traffic density without resulting in traffic congestion problems using pervasive computing infrastructure.

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