VEHICLES DRIVERS' BEHAVIOURAL PATTERN AND TRAFFIC CONGESTION ON NIGERIA ROADS

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ABSTRACT

Road traffic congestion is a problem in many countries including Nigeria. We identify some unusual drivers' behaviour. A review of the literature shows that drivers' behaviour causes road traffic congestion. A mathematical model has been developed to give quantitative description of effect of a driver blocking the road. The pieces of information generated by our model are useful for developing Intelligent Transportation System (ITS).

INTRODUCTION

Congestion on our roads has become a common phenomenon. Some observed effects o f congestion on road traffic flow are: gridlock, increased delay, loss in productivity, damage to vehicles as a result of accidents, increased engine and mechanical wear, increase in energy consumption which in turn increases air pollution and carbon dioxide emissions irregular acceleration and braking (Kurzhanskiy and Varaiya, 2010).

Several attempts have been made to identify the main causes of road traffic congestion. (Omiunu (1998), Zhao and Chung (2001), Oni (2010) and Zilute *et al.* (2010)). Congestion can be caused by the occurrence of incidence such as traffic accidents, vehicle disablements, spilled loads and hazardous materials. According to Baykal-Gursoy *et al.* (2009), over half of congestion in urban areas and a high proportion of road traffic congestion in the rural areas are attributed to incidents especially nonrecurring traffic congestion. Aworemi *et al.* (2009) summarised that congestion is caused by one or a combination of these: Social and economic factors, Road factors, vehicle factors, human factors; and accident factors.

In this paper, we present models that can be used to describe the effect of drivers' behaviour on road traffic congestions in Nigeria. Several definitions of deviant driving behaviours have been proposed in literature, Rozmi *et al*. (2009). Tasca (2000) summarises a driving behaviour to be aggressive or deviant "if it is deliberate, likely to increase the risk of collision and is motivated by impatience, annoyance, hostility and/or an attempt to save time." Some specific deviant driving behaviour include: tailgating, weaving in and out of traffic, passing on the road shoulder, failure to yield the right of way to other road users, road rage, improper lane changes, frequent and abrupt lane changes, blocking of roads by drivers, etc.

Bayal-Gursoy *et al*. (2009) used Markovian queuing theory to model the traffic flow on a road way link subject to incidents. They obtained the steady-state distribution of the number of vehicles on a road link using the m/m/s and m/m/∞ queuing systems. Their method and results are similar to those of Kakooza *et al*. (2005) using probability generating functions. They argued that there are conditions where a road way link can accommodate hundreds of vehicles. Using probability generating functions, they gave the expected no of vehicles in the system as:

$$E(X)=\frac{\lambda[(r+f)^2+\mu_0 f]}{(r+f)[r(\mu_0-\lambda)-\lambda f]} \tag{1}$$

(Where μ_0 is the service rate without delay; λ is the average number of vehicles arriving at an intersection per unit time; r is the rate of disappearance or clearance of the delays; and f is the rate of occurrence of delays respectively. However, the results presented are for very low traffic intensity and did not identify the dramatic over-flow arising from road blockage in real life.

When there is a gridlock, Baykal-Gursoy *et al.* (2009), Daganzo (1994) and Kakooza *et al.* (2005) did not capture the effect of drivers blocking the road, but assume first-in-first out and that overtaking is not allowed. A model to describe the effect of drivers blocking the road is therefore appropriate; Ben-Akiva and Bierlaire (1999). Rozmi *et al.* (2009) considered road rage as one of the most prominent and common phenomenon experienced by motorists especially for those who live in big cities in recent years.

In the model proposed by Daganzo (1994), a cell is not allowed to be congested. It was assumed that vehicles can always escape to infinity. But we have observed that in practice, a cell can become congested as a result of a driver blocking the exit route of the cell.

THE CELL TRANSMISSION MODEL

Traffic flow is usually treated as a fluid in classical methods to explain its macroscopic behaviour. Based on the assumption that the number of vehicle is conserved between any two points if there are no entrances or exits, Lighthill and Witham (1955) and Richards (1956), commonly referred to as the LWR model. In the LWR model, densities, speed values and flows were defined as continuous variables in each point in time and space. The first order Partial Differential Equation (PDE) from this model is:

$$\frac{\partial q}{\partial x} + \frac{\partial k}{\partial t} = 0, \qquad (2)$$

Crucial to the approach of Lighthill and Witham was the fundamental hypothesis that flow is a function of density and speed:

$$q = f(k, x, t) \qquad (3)$$

Where q is the traffic flow, k is the density, $x \; and \; t$ are the space and time respectively. In other words, the flow in a short distance changes at a rate equal to the difference between inflow and outflow. Equations (2) and (3) describe the relationship among the traffic flow, density, time and space.

Lighthill and Witham (1955) assumed that the fundamental hypothesis holds at all traffic densities, not just for light-density traffic but also for congested traffic conditions. Daganzo (1994, 1995) gave a simplified discrete approximate solution to equation (2) by giving the relationship between q and k:

$$q = \min\{vk, q_{max}, v(k_j - k)\}, \;\; 0 \leq k \leq k_j \qquad (4)$$

Where v is the free flow speed, k_j is the jam density and $q_{max} \leq \frac{k_j v}{2}$ is the maximum flow (inflow capacity).

Cell Transmission Model (CTM) assumes that the road link can be divided into lengths of equal size called cells such that the cell length is equal to the distance a single vehicle will travel in one-time step at the free flow speed. (Lo, 1999 and Wang, 2010). CTM is a discretised macroscopic model which deals with road traffic as if it were a fluid. Under light traffic, all vehicles in a cell can travel to the next cell without delay with each tick of the clock time. i.e. $x_{i+1}(t+1) = x_i(t)$ for $t = 0,1,2, \ldots$ (5)

With delays, Daganzo (1994, 1995) introduced two constants: Q (the flow capacity) and X (the cell holding capacity), and showed that the Lighthill, Witham and Richards (LWR) equation can be approximated by the recursive equations:

$$x_i(t+1) = x_i(t) + y_i(t) - y_{i+1}(t) \qquad (6)$$

Where i = number of cells

$x_i(t)$ = the number of vehicle in cell i at time step t,

$y_i(t)$ = the flow of vehicle into cell i from $i - 1$ at t.

Equation (6) is called the flow conservation equation.

That is: 'Occupancy = Storage + Inflow – Outflow.'

In time step t, if $x_{i-1}(t)$ is the number of vehicles in cell $i-1$; $Q_i(t)$, the maximum number of vehicles that can enter (the inflow capacity of) cell i, and $\{X_i(t) - x_i(t)\}$ the available space in cell i; then $y_i(t) = \min\{x_{i-1}(t), Q_i(t), [X_i(t) - x_i(t)]\}$ (7)
Where $X_i(t)$ is the number of vehicle that can fill a cell *i* at time step *t*

CTM is capable of modelling oversaturated traffic flow; Lo (1999) and Lo et al. (2001). CTM was used to propose a traffic signal control formulation using the integer programming technique. In the application, the formulation was limited to a one-way street, and turning movements were not considered.

Wang (2010) developed the Conditional Cell Transmission Model (CCTM) with improvement on the CTM. He expanded the CTM to incorporate the two-way arterial and taking into account diverge and merge activities at intersections. Also, a conditional cell was introduced to simulate periodic spillback and blockages at an intersection. However, he did not consider the variations of the built-in parameters like the cell length, the cell holding capacity and the flow capacity of the individual cell. The assumption is that these parameters are constant.

PARAMETERS OF THE CTM

(A). Length of the cell, L. $L = vt$ (8)
Where v is the free flow speed (km/hr), *t* is the length of the time step (seconds).

(B). Cell Holding Capacity, *X*. $X = LK_j$, $X_i = X$ for all cells. (9)
Where;
X = the number of vehicles that can fill a cell, L = Length of cell,
K_j = Jam density (veh/km/lane). This is also known as the maximum density. I.e. the number of vehicles per unit of distance observed under jam condition.

(C). Flow capacity of cells, Q . $Q = st$ (10)
Where; Q =Maximum number of vehicles that can flow into or out of cell *i* at time step *t*.
s = Saturation flow rate (veh./hr), {maximum number of vehicle per hour per lane when flow is saturated}, *t* = time step (sec).

EMPIRICAL OBSERVATION

In the calibration of the CTM and CCTM, it assumes that parameters like $Q_i(t)$ and $X_i(t)$ are constant throughout the simulation period. However, many factors (drivers' behaviour, vehicle characteristics, weather conditions, road location/geometry, etc.) can affect the traffic flow. In CTM, it assumes that driving rules are obeyed, no overtaking, etc. (Fig. 1). We have observed that in some cases, rules are not obeyed and drivers drive to obstruct others, (Fig. 2):

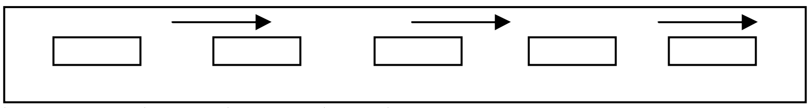

Fig.1: A road segment where rules are obeyed.

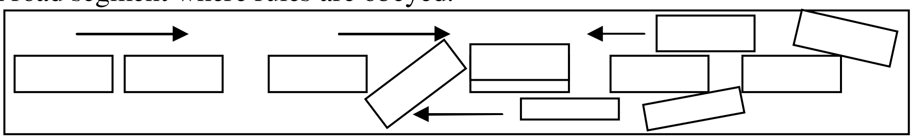

Fig.2: A road segment where rules are disobeyed. (Appendix B).

MODEL FORMULATION: ASSUMPTIONS

We assume that even though there are cells of equal lengths, the jam density will not necessarily be the same due to some drivers' behaviour such as: driving against traffic, parking on the road, blocking of roads in order to gain entrance to another lane, hence changes in $X_i(t)$ will occur. We consider the following definitions:

(i). Let $X_i(t) = X_i^n(t), n = 1,2,3.$

$$X_i^n(t) = \begin{cases} X_i^1(t), & if\ cell\ is\ affected\ by\ drivingagainst\ traffic. \\ X_i^2(t), & if\ cell\ is\ affected\ by\ indiscriminate\ parking. \\ X_i^3(t), & if\ cell\ is\ affected\ by\ condition\ of\ the\ road. \end{cases} \quad (11)$$

I.e. the cell holding capacity can be made to depend on the above factors at the individual cells at different time steps.

(ii). Let $m_i(t) = \begin{cases} 1, if\ no\ blockage \\ 0 < m_i(t) < 1\ , if\ partial\ blockage, \\ 0\ , if\ total\ blockage. \end{cases}$ (12)

where $m_i(t)$ is the control parameter that account for the stochastic nature of Q in cell i, at time step *t*. If cell is not blocked, then $Q_i = Q$, if the cell is partially blocked, then $Q_i = m_i(t)Q$, where $0 < m_i(t) < 1$. If the cell is totally blocked, then $Q_i = 0$ e.g, when driving against traffic, we can have: $Q_i = \frac{1}{2}Q$, i.e. $m_i(t) = \frac{1}{2}$ for 30sec, $m_i(t) = 1$ for the next 20s or zero.

MODEL FORMULATION

(a). A road segment.

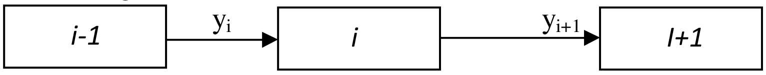

Fig. 3: Road segment.

From Figure 3, the flow conservation and advancement equations for the CTM are given as:

$$x_i(t+1) = x_i(t) + y_i(t) - y_{i+1}(t) \quad (13)$$

And $y_i(t) = \min\{x_{i-1}(t), Q_i(t), [X_i(t) - x_i(t)]\}$ (14)

Introducing the control parameter of definitions (i) and (ii) in eqn. (14), we have:

$$y_i(t) = \min\{x_{i-1}(t), m_{i-1}(t)Q_{i-1}(t), m_i(t)Q_i(t), [X_i^n(t) - x_i(t)]\} \quad (15)$$

(b) A road junction.

Consider a network of roads, two scenarios usually occur. There is either a road merging or a road diverge (folk topology). For a road diverge, we have:

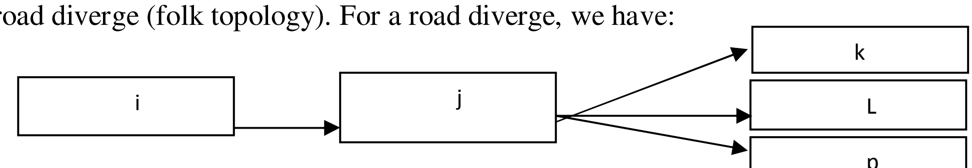

Fig. 4: Diverging cell structure.

A junction can either be controlled (signalised), or not controlled (seeking gap acceptance). For a controlled intersection, the inflow capacity ($Q_i(t)$) is affected by the signal timing (i.e. the red and green phase respectively), Lo (1999), and Chow and Lo (2007).

Mathematically:

$$Q_i(t) = \begin{cases} s\ t\epsilon\ green\ time \\ 0\ t\epsilon\ red\ time. \end{cases} \quad (16)$$

From Fig.4, we have the flow advancement equation as

$$y_{k+l+p}(t) = \begin{cases} x_j(t), \\ m_j(t)Q_j(t), \\ \frac{\min\left[m_k(t)Q_k(t), \left(X_k^n(t) - x_k(t)\right)\right]}{\beta_j^1}, \\ \frac{\min\left[m_l(t)Q_l(t), \left(X_l^n(t) - x_l(t)\right)\right]}{\beta_j^2}, \\ \frac{\min\left[m_p(t)Q_p(t), \left(X_p^n(t) - x_p(t)\right)\right]}{\beta_j^3} \end{cases} \quad (17)$$

Where $y_{k+l+p}(t)$ is the flow of vehicle from cell j to cells k, l and p. $\beta_j^r, r = 1,2,3.$ is the split ratio of cell j at time step t. Also, $\sum_r \beta_j^r = 1$, (Lo et al. 2001) (18)

Therefore,

$$y_k(t) = \beta_j^1(t) y_\theta(t), \qquad y_l(t) = \beta_j^2(t) y_\theta(t) \qquad y_p(t) = \beta_j^3(t) y_\theta(t) \tag{19}$$

And $y_\theta(t) = y_{k+l+p}(t)$ (20)

Clearly, equations (13), (15), (17) and (19) present the conservation and advancement flow equations with varying parameters $Q_i(t)$ and $X_i(t)$ respectively.

If the road segment is signalised, equation (12) will reduce to:

$$m_i(t) = \begin{cases} 1, for\ a\ green\ phase \\ 0, for\ a\ red\ phase. \end{cases} \tag{21}$$

Equation (21) is consistent with (16).

APPLICATION

We present two applications of our model. The first application employs the data presented by Wang (2010) where $X_i(t)$=13, $x_i(t) = 10$. Table 1 shows the congestion in a cell in front of an intersection using Wang (2010). Now we assume m(t) = ½ and m(t) = 0.

Table 1: Number of vehicles in a cell at an intersection when $Q_i = m_i(t)Q$ (effect of road blockage) and total blockage (compared with Wang, 2010.).

Time steps (seconds)	Wang (2010)	$m(t) = \frac{1}{2}$	$m(t) = 0$
1	10	10	10
2	13	13	13
3	8	11	13
4	7	13	16
5	6	14	18
6	6	14	18
7	6	14	18
8	6	14	18
9	4	15	21
10	3	16	23

In Table 1, column 1 shows the different observation time for a cell in front of an intersection. Column 2 shows the number of vehicles in the cell using Wang (2010) model. Column 3 shows the number of vehicles in the cell when m(t) = ½ while column 4 shows the number of vehicles in the cell when m(t) = 0. m(t) = 0 means, no movement of vehicles out of the cell, m(t) = ½ shows partial movement out of the cell. The congestion in column 4 is higher than that of column 3. This is as a result of the differences in the choice of $m_i(t) = 0$. While congestion is expected as a result of road blocking, our model gives numerical information on the effect of road blocking. The numerical information can be used to developing relaxation time (Omosigho and Igbinosun, 2004) and also Intelligent Transport System (ITS).

In our second example, we use data from Daganzo (1994).We consider a road segment with traffic light having a fixed cycle length, and $m(t) = 0$ (total blockage). From results presented (see cell $i+1$ in figure 3 and table 2), it shows the level of congestion for cells 1, 2 and 3 respectively. Observe that there is total blockage at the end of cell 2 (cell i in figure 3) and it attains maximum number of vehicles allowed in time step 4 while cell 1 attains maximum allowed in time step 7. This is due to the fact that naturally cell 2 will be the first to attain maximum value. Our model can be used to predict when cell 1 will be filled as observed from table 2. When there is total blockage of traffic flow in cell 2 with a time step of 30seconds each, graph 2 shows that at the start of simulation, there is a gradual build-up between points A and C in cell 1 for the first 120 seconds with the number of vehicles increasing from 20 to 25 in the cell. Then there is a rapid increase in the number of vehicles from 25 to 75 between point C and F. While it takes 210s to attain a gridlock in cell 1, it takes 120s before a gridlock is noticed in cell 2.This rapid increase is noticed at points A to E. Note that there is an empty space in of cell 3 (graph 2), this is expected due to the inability of vehicles to leave cell 2, and hence cell 1 and cell 2 get filled up in 210s and 120s respectively. The cell remains empty for the simulation period. It takes 60 seconds for the cell to empty out. This scenario is observed in real life when there is blockage to the road due to drivers' behaviour. When the time step is 6 seconds and there is a traffic light at the end of cell 10 (graph 6), result obtained in cells 9, 10 and11respectively show similarity with cells 1, 2, and 3 when the time step is 30s and the existence of total blockage at cell 2. The difference is that there is one vehicle in the cell after 60s of red phase and the beginning of green phase. The number never gets higher than one because of the length of the green time.

Table 2: Number of vehicles in various cells at time step *t*.

Time step(sec)	cell 1	cell 2	cell 3
1	20	20	20
2	20	40	0
3	20	60	0
4	25	75	0
5	45	75	0
6	65	75	0
7	75	75	0
8	75	75	0
9	75	75	0
10	75	75	0
11	75	75	0
12	75	75	0
13	75	75	0
14	75	75	0
15	75	75	0
16	75	75	0
17	75	75	0
18	75	75	0

When the time step is reduced to 6s, there are 15 cells in the network and 4 vehicles are initially in each cell at the start of simulation. Consider the introduction of a traffic light at the end of cell 10 with cycle length of 3min (1min red time and 2min green time). The number of vehicles in cell 14 was stable at 4 for the first 24s. It reduces to zero in 30s and remained so until the 78^{th} s (Point A in graph 7). Points B, C and D, respectively show fluctuations between zero and one vehicle in the cell. This empty cell shows that the number of vehicles decreases rapidly due to the short time it takes to release vehicles in it. This result is similar to that obtained in Wang (2010) for a cell in front of an intersection. The change in time scale and the results obtained shows the usefulness of our model.

CONCLUSION AND RECOMMENDATION

Cases of driving on the edge of the road, and driving against traffic are not uncommon. We describe traffic flow on several road segments and identify some unusual drivers, behaviour. Model to capture effects of drivers' behaviour on road traffic congestion is reported. In general, unwholesome drivers' behaviour increases congestion on the road and induces driving rage. In this study, results show that the number of vehicles increases due to drivers' behaviour. Interestingly, the pattern of flow in a cell with traffic light, partial and total blockage show a sharp rise in the number of vehicles in the cell before a relapse set in (Appendix A). For example, 75 vehicles can be in the cell for a time step of 30s. A comparison with existing model shows that blocking of a lane can immediately cause congestion. Therefore, we recommend that efficient methods (Variable road signs, road lane priorities can be used to remove some vehicles from the road so as to reduce the volume of vehicles on the road.) should be put in place to ensure that blocking is not permitted. Where blockade occurs it should be removed as soon as it occurs. The study shows that the first step to ameliorating the effect of bad driving behaviour it to reduce their occurrence so that there will be free flow of traffic. The driving behaviour of blocking the road reduces the speed of vehicles.

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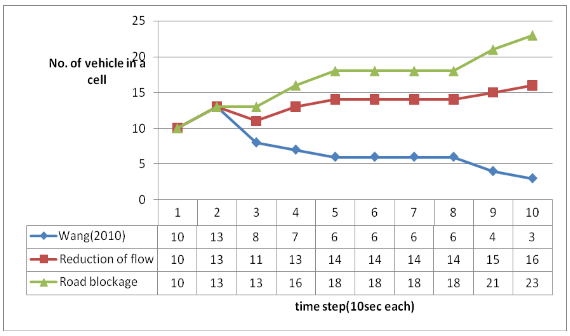
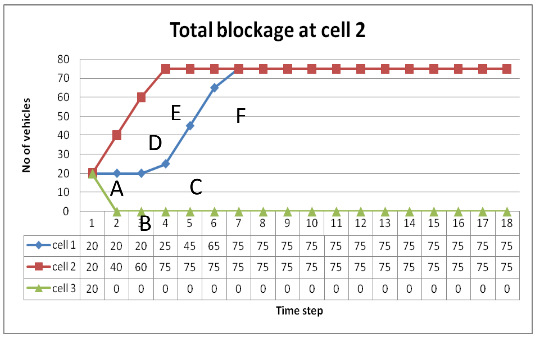
APPENDIX A.



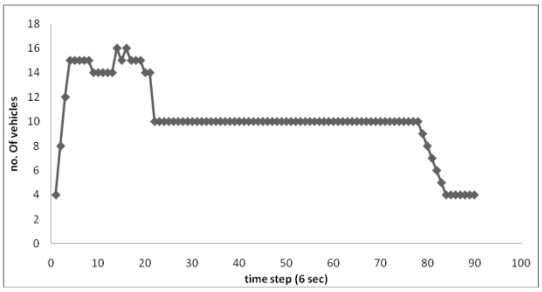
	1	2	3	4	5	6	7	8	9	10
Wang(2010)	10	13	8	7	6	6	6	6	4	3
Reduction of flow	10	13	11	13	14	14	14	14	15	16
Road blockage	10	13	13	16	18	18	18	18	21	23

Graph 1: Cell at an intersection when Wang (2010), $Q_i = m_i(t)Q$ (effect of road blockage) and total blockage.

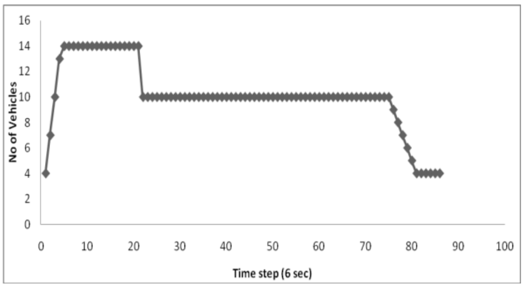


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
cell 1	20	20	20	25	45	65	75	75	75	75	75	75	75	75	75	75	75	75
cell 2	20	40	60	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
cell 3	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

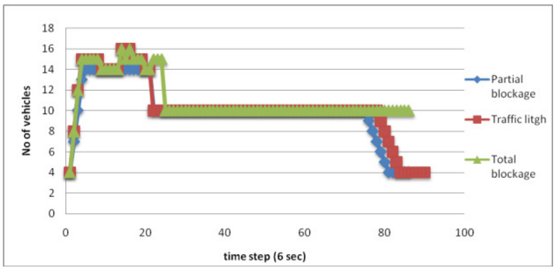
Graph 2: Total blockage at cell 2 (30sec time step)



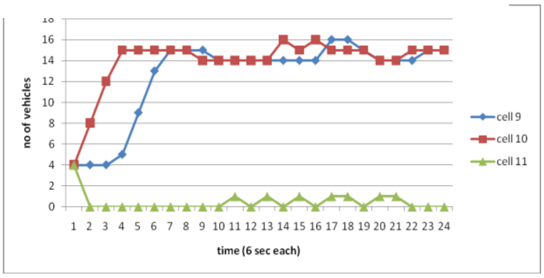
Graph 3: Cell with traffic light



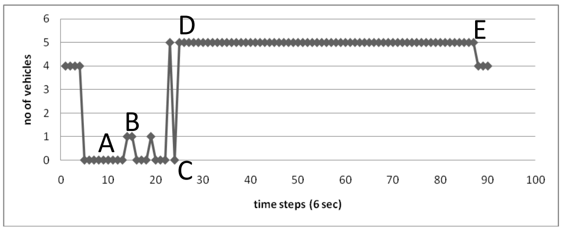
Graph 4: Cell with Partial blockage



Graph 5: Cell with traffic light, partial and total blockage

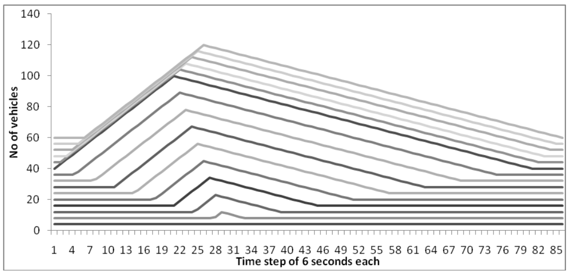


Graph 6: Total blockage at cell 10 (6sec time step)

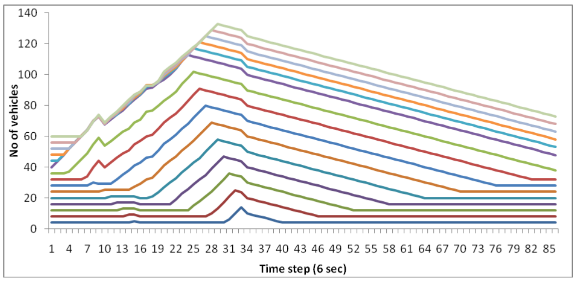


Graph 7: Number of vehicles in a cell after a traffic light.

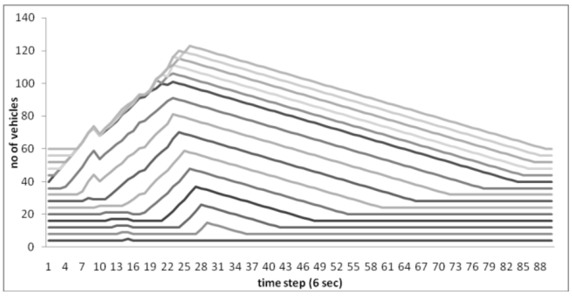
N.B: The time step is 6 seconds, the cycle length is 3min (1min red time and 2min green time). This is the evolution of traffic in a road segment with a traffic light at the end of cell 10.



Graph 8: Fundamental diagram of cells with partial blockage



Graph 9: Fundamental diagram of cells with total blockage



Graph 10: Fundamental diagram of cells with traffic light

APPENDIX B.

Plate 2: Gridlock scene in Benin City, vehicle XX is blocking the road.

Plate 1: Vehicle X blocking the road and preventing others from proceeding.

Plate 4: Vehicle Y is wrongly reversing inside congestion and causing others to a standstill.

Plate 3: Vehicle 'AA' blocking the road and preventing others behind from proceeding